GUIDELINES FOR THE PREPARATION OF START-UP, COMMISSIONING, AND MONITORING PROCEDURES: ENGINEERED LIQUID LOOP SOLAR HEATING SYSTEMS

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Information, additional copies

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1.0 INTRODUCTION

This manual is intended for engineers designing liquid loop solar heating systems.

This document presents general guidelines and procedures for solar systems in the areas of:

- Start-Up and Commissioning
- Operational Monitoring
- Troubleshooting
- Performance Monitoring

With this document as a guide, the design engineer is expected to specify the instrumentation and test points required for his particular design, and to produce the appropriate documentation, including commissioning documents, operational monitoring procedures, troubleshooting documents, and performance monitoring reporting forms.

1.1 How To Use This Manual

This manual deals with each major area of:

2.0 Start-Up and Commissioning
3.0 Operational Monitoring
4.0 Troubleshooting
5.0 Performance Monitoring

Each of the above are dealt with in separate sections as indicated by the numbering. Each section outlines detailed requirements for the particular procedures to be followed and the documentation that must be produced.

Within each section is a basic "menu" for producing the appropriate documentation. In many cases, the system designer can simply use this as a draft of the documentation for his particular system and edit it to suit his design. Blanks indicated by a grey overtone are to be filled in by the design consultant, other blanks will be filled out on-site by the persons carrying out the procedures specified.

In many cases, instrumentation and test point requirements are duplicated. For this reason, specification of the instrumentation and test points required for those procedures are covered in common appendices.

Appendix A outlines the method to be used for dividing a solar system into modules for the purpose of instrumentation and specifies the detailed instrumentation and the test points required for each module.

Appendix B gives detailed specifications and installation requirements for the various types of instruments.

The following checklist will be helpful in carrying out the various steps required.

Step	Reference Section
1. Break the system design into modules and determine the instrumentation requirements.	Appendix A
2. Review instrumentation specifications and installation instructions. Select instrumentation and incorporate it into the solar heating system design.	Appendix B
3. Produce start-up and commissioning procedures.	Section 2
4. Produce operations manual.	Section 3
5. Produce troubleshooting chart.	Section 4
6. Prepare specifications for the performance monitoring equipment. Incorporate the performance monitoring equipment into the solar system design.	Section 5

1.2 Description of Procedures

Start-Up is a series of tests and inspections conducted by the system contractor and witnessed by a representative of the owner of the system. The system design consultant should be present. These tests and inspections are performed during and immediately following construction to ensure that the system and its components are correctly installed and capable of operating at specified levels, and hence, that the system is capable of being commissioned. The testing includes:

- component testing during construction,
- assurance that major components can operate at specified levels,
- actual start-up of the system,
- initial system adjustments.

This procedure also includes checking the instruments and test points required to carry out the commissioning procedures.

Commissioning consists of a number of discrete tests. The successful completion of these tests, as well as any required corrective action, should ensure that the installed system meets the design specifications. These tests include:

- flow rate and direction tests,
- collector flow establishment and balancing,
- freeze protection operation,
- operation of heat exchangers and controls.

In Section 2.0 Start-Up and Commissioning, methods and procedures for the necessary tests are described.

Operational Monitoring is performed by the system operator. Its function is to detect operating problems or a decrease in the performance of the system. The methods employed for this include:

- regular inspections of the system and instrument readings,
- monthly recording of instrument data and comparing it with design specified ranges from the commissioning report,
- detailed semi-annual checks of specific components,
- component checks and preventive maintenance checks.

Section 3.0 entitled Operational Monitoring provides a framework for the development of operator's handbooks for any specific liquid loop solar system design.

Troubleshooting, dealt with in Section 4.0, involves the diagnosis and correction of system operationing problems or malfunctions. System problems should be initially identified by the system operator through the operational monitoring schedule. In the section on troubleshooting, a chart for use in identifying the likely cause of typical operating problems is presented. Also included are in depth discussions on some typical problems and solutions for components of solar systems as an augmentation to the detailed troubleshooting chart.

Performance Monitoring consists of the metering of energy quantities to determine performance indicators. The desired result is to identify the energy contributed to the load by the solar system. It may be necessary to record other readings in order to calculate this result.

1.3 Example Systems

To assist system designers in using this manual, a number of examples are presented. These examples include both closed loop and drainback systems used for both space and hot water heating. These examples are for illustrative purposes only and are not recommended designs.

The three completely hypothetical systems used to illustrate the use of this manual are referred to as systems A, B, and C. Descriptions of these systems and the completed instrumentation selection and documentation of procedures are available as a separate volume entitled "Examples of the Preparation of Start-Up, Commissioning and Monitoring Procedures for Engineered Liquid Loop Solar Heating Systems."

System A

ACE ATHLETIC ASSOCIATION
CAFETERIA AND RECREATION COMPLEX
Solar Domestic Hot Water Heating System

This system is a basic domestic hot water or process hot water heating system with a closed loop glycol collection loop.

The auxiliary heating system consists of an electrically heated tank.

System B

E.G. INDUSTRIES
Solar Process Water Heating System

This system is a simple domestic hot water or process hot water heating system with a drainback water collection loop.

The auxiliary heating system consists of a steam heated boiler.

System C

GRAYSTONES PUBLIC SCHOOL
Solar Space and Domestic Hot Water Heating System

This system is a relatively complex combined space and water heating system with a closed loop glycol collection loop. Space heating is accomplished using a fan coil unit in the glycol loop.

Auxiliary water heating is electric.

2.0 START-UP AND COMMISSIONING

Based on the procedures outlined in this section, the designer of a solar heating system is expected to produce start-up and commissioning documents tailored to his specific system. The final start-up and commissioning documents will include those sections of the following procedures which apply to that design.

2.1 MENU FOR PRODUCING A START-UP DOCUMENT

2.1.1 General Introduction to Start-Up Document

2.1.2 Site Inspection
- Preparations
- Collectors
- Piping
- Insulation
- Thermal Storage
- Electrical

2.1.3 Verification of Glycol Properties
- Preparations
- Responsibilities
- Lab Tests
  - Test No. 1 - Reserve Alkaiinity
  - Test No. 2 - Concentration Ratio
  - Test No. 3 - pH Level

2.1.4 Differential Controller Tests
- Preparations
- Responsibilities
- Scheduling
- Test No. 1 - Fail Safe Operation
- Test No. 2 - Differential Setting
- Test No. 3 - Drainback Test

2.1.5 Motor and Pump Test
- Preparations - Motor
- Preparations - Pump
- Responsibilities
- Scheduling
- Direction of Rotation
- Motor - Amperage
- Pump - Circulation Test

2.1.6 Leak Test

2.1.7 Final Visual Inspection

2.1.8 Flow Balancing

Preliminary Information

Collector Loop Flow Rate

Collector Bank Flow Rates

Final Flow Adjustment

Note: Italics are used to indicate direct instructions to the system designer.

2.1.1 General Introduction to Start-Up Document

Start-up is a series of tests and inspections performed during and immediately after construction to ensure that the system and its components are installed correctly, and are capable of operating at specified levels.

The following tests are performed during and immediately following the construction phase of the project. Since component testing does not require the system to be in a completed and operational mode, the component tests may be done immediately following the installation of the component. In cases where various pre-conditions must be met in order to perform the test, testing should be done at the earliest possible date following the installation of these components. When the system has been fully constructed, a final visual inspection and system flow checks should be performed.

Supportive documentation must be prepared following each test or series of tests. This documentation will be maintained in a project file and summarized when the testing is complete. This documentation will help the owner in his final assessment of the system.

Testing may be done whenever components are made available for testing. It is not necessary to test them in the order the tests are described.

2.1.2 Site Inspection

Preparations

- obtain a copy of the design specifications, design drawings and shop drawings;

- obtain copies of the manufacturer's specifications for all major components in the system (collectors, pumps, heat exchangers, controllers, control valves);

- prepare an "inspection" checklist. This should be a specification sheet that details the components that should be installed. This sheet will be updated and dated following each inspection;

- the contractor should attach a sticker to pump timers indicating:

    - the date the system became fully operational,
    - the pump timer reading on that date.

Collectors

- verify that the number and type of collectors specified in the shop drawings have been installed;

- verify that the collectors have been installed in accordance with the designer's and manufacturer's recommendations;

- verify that the collectors are fed from the bottom and returned from the top (except for thermal diode or vacuum tube collectors);

- if any expansion couplings have been used in the array, ensure that adequate play is available for both full expansion and full contraction;

- check the security of all fasteners including those holding the collectors to the support structure, and those used in assembly of the support structure;

- ensure that load spreading washers have been used where necessary on collector attachment points;

- verify that flashings are firmly supported;

- ensure that there is a isolating gasket between any aluminum collectors and a steel frame.

Piping

- verify that all pipes, valves and fittings have been installed as specified;

- ensure that gate valves are used only for fully open or fully closed applications;

- verify that the pump is physically connected in the proper flow direction;

- verify that pumps have an adequate suction head. In drainback systems, the pump must be below the water level in the tank on start-up;

- verify that the heat exchanger connections are made in the proper direction;

- on closed loop systems, verify that the expansion tank is on the suction side of the pump;

- verify that the pressure rating of the relief valve on the glycol loop is higher than the system pressure, but not higher than the rated pressure of the expansion tank;

- ensure that the collectors cannot be isolated from the expansion tank or pressure relief devices by closing valves;

- on drainback systems, verify that all pipes to and from the collectors are sloped 1 in 48, or better;

- on closed loop systems, ensure that drain valves are located such that all piping can be drained;

- if a back flow preventor is used, verify that there is an expansion tank between it and the storage tank;

- since a back flow preventor may discharge fluid, verify that it is not installed near any electrical components which might be damaged;

- if the pump is a variable speed type, verify that it is set as recommended by the manufacturer;

- verify that there are sufficient pipe hangers, supports and expansion devices to compensate for thermal effects.

Insulation

- verify that the levels of insulation are as specified;

- verify that all insulation is:

    - securely fastened,
    - appropriately weatherproofed and protected from physical abuse,
    - protected from ultra-violet degradation (if applicable).

- verify that all test points are properly insulated;

- verify that any seams on piping jackets point downward to prevent moisture penetration;

- verify that there is insulation on the underside of storage tanks;

- verify that insulation does not impede the proper cooling of motors.

Thermal Storage

- verify that the storage tank is as specified or designed;

- verify that the pressure relief valves are installed and set to protect the system component with the lowest pressure rating;

- if a non-toxic fluid is specified, verify that a label is affixed in the vicinity of the fill valve, indicating that only non-toxic fluid be used.

Electrical

- verify that temperature sensors are firmly supported and protected from physical damage;

- ensure that all sensor wiring is protected from physical damage;

- verify that controls are located such that accidental adjustment is not possible;

- verify that wiring is installed according to local electrical codes;

- ensure that the instrumentation required for commissioning is available and properly installed.

2.1.3 Verification of Glycol Properties

Preparations

- the working fluid is tested to ensure that the mixture in the system will provide the required freeze protection, and that the fluid is of the proper type;

- it is important that ethylene glycol not be used in systems where contamination of potable water is possible;

- prepare a tabulation of the specified glycol properties:

  - type of antifreeze
  - concentration - % antifreeze
    (by volume) - % water
  - acidity - pH
  - reserve alkalinity, minimum

- the solution should have circulated for at least 30 minutes to assure that the sample is representative.

Responsibilities

- the contractor shall drain a small sample of the heat transfer fluid from the system for testing. The sample shall be sent to a lab for analysis and a copy of the test report sent to the owner or to his appointed representative.

Lab Tests

Test No. 1 - Reserve Alkalinity

- determine the amount of alkaline inhibitors present in the antifreeze solution by means of a reserve alkalinity test.

The test should be conducted in accordance with ASTM D 1121-72 Reserve Alkalinity of Engine Antifreeze, Antirusts and Coolants:

- check the specific antifreeze manufacturer for the desired reserve alkalinity and the method of restoring the solution to the required level;
- Example: Dow recommends adding dipotassium phosphate to the glycol solution if the reserve alkalinity falls below 9.0. The level should be maintained in the range of 10 to 12.

Reserve Alkalinity as measured in test _____

Test No. 2 - Concentration Ratio

- determine the antifreeze to water concentration of the solution:

  - the concentration may be obtained with a hydrometer, refractometer or by the ASTM E 203 - 75 - Water using Karl Fischer Reagent.

Concentration as measured in test - _____ % antifreeze
- _____ % water

Test No. 3 - pH Level

- determine the acidity of the solution in accordance with ASTM D 1613 - 66 (Reapproved 1972) - Acidity in volatile solvents and chemical intermediates used in paint, varnish, lacquer and related products.

pH level as measured in test _____

2.1.4 Control System Tests

Control systems for solar heating systems vary widely in their configuration and modes of operation. For this reason, it is not practical to provide detailed start-up procedures here. Procedures, however, are given for basic differential controllers that might be used for systems with simple control strategies.

For systems not covered by the simple procedures listed here, it is the design engineer's responsibility to ensure that adequate test procedures are produced for his control system design. In producing these start-up and test procedures the following concerns must be addressed:

- *Is the control system fail safe?*
- *Are the set points for the various control functions properly set, including the freeze protection settings?*
- *Are the sensors accurately representing the temperatures that they are intended to indicate?*

The fail safe operation of a solar system is extremely important and falls into several categories. Should a control sensor either open circuit or short circuit, the system must fail safe to an off position. Should power be lost to a drainback system the system must drain automatically. The mechanical failure of a system component, such as a pump, must not jeopardize the rest of the system.

The procedure outlined below is directly applicable to controllers using thermistors for sensing temperature. Some controllers use integrated circuit sensors for measuring temperatures. Integrated circuit temperature sensors produce either a current or a voltage proportional to the temperature. In these cases, the following procedure should be modified using the manufacturer's instructions in order to produce the same results. Before the sensors are tested, they should be cycled several times through their complete operating range.

In all cases, suspect sensors can be checked against a known return temperature such as an ice bath or boiling water.

Preparations

- obtain a copy of the temperature sensor characteristic curve from the manufacturer (resistance vs. temperature);

- obtain variable resistors which can be substituted for the system temperature sensors. These resistors can either have a built-in means of reading the set resistance or can be standard potentiometers from which the resistance can be determined using an accurate resistance meter. The variable resistors should have a range of 0 to 100,000 ohms;

- the controller should be wired for power.

Responsibilities

- the tests shall be the responsibility of the contractor;

- all testing will be witnessed by the owner or by his appointed representative and the design consultant.

Scheduling

- the tests will be performed following the installation of the controller and temperature sensors;

- the tests may be conducted at any level of solar insolation and system flow.

Test No. 1 - Fail Safe Operation

- switch off the electrical power to all pumps and/or control valves;

- verify that the controller is receiving electrical power;

- test the controller for short circuit protection (zero resistance).

With a test light on the leads to the pump or to the control valve it operates, short circuit the temperature sensor leads. The test light should not come on;

- test the controller for open circuit protection (infinite resistance). With a test light on the leads to the pump or to the control valve it operates, open circuit the temperature sensor leads. The test light should not come on.

Test No. 2 - Differential Setting

- switch off the electrical power to pumps and/or control valves;

- set the differential controller for the recommended temperature differential;

Specified temperature differential on [redacted] °C
off [redacted] °C

- follow the specified procedure and record the readings in the chart on the following page;

- disconnect collector and tank sensors at the controller and substitute with appropriate variable resistors. The resistors can be connected to the sensor terminals at the controller;

- from the temperature sensor characteristic curve, determine the resistance associated with 5°C absolute temperature;

- dial this resistance into the variable resistor on the output to the tank sensor. Record the resistance;

- with the controller set in the automatic position, gradually change the resistance on the collector variable resistor until an output is measured at the controller output terminals (to pump or control valve). Record the indicated resistance;

- vary the resistance until there is no longer an output at the controller output terminals. Record the indicated resistance;

- calculate the differential resistance and, from the temperature sensor characteristic curve, determine the temperature differential;

- compare this with the original setting of differential temperature using the following equation:

$$\frac{100\% \times \text{differential temperature setting} - \text{differential temperature}}{\text{differential temperature setting}} = _____\%$$

- reset the tank variable resistor for the resistance associated with a 15°C absolute temperature and repeat the above procedure.

Tank Sensor = 5°C

Tank Sensor	Collector Sensor		Differential	Temperature Differential	% Temperature Difference
_____ohms	on:	_____ohms	_____ohms	_____°C	_____
	off:	_____ohms	_____ohms	_____°C	_____

Tank Sensor = 15°C

Tank Sensor	Collector Sensor		Differential	Temperature Differential	% Temperature Difference
_____ohms	on:	_____ohms	_____ohms	_____°C	_____
_____ohms	off:	_____ohms	_____ohms	_____°C	_____

- if the percent temperature difference is substantial (more than ten percent), for any of the four tests, adjust the controller setting and repeat the above test.

Test No. 3 - Drainback Test

- a drainback test shall be performed on all systems using a drainback operation for freeze protection;

- note the level of the heat transfer fluid in the solar storage tank site glass with the collector loop fully drained;

  Level (with respect to marked line) _____ cm

- circulate the heat transfer fluid through the collectors for a minimum of fifteen minutes to ensure that all collectors are fully wetted;

- switch off electrical power to the collector loop pump(s). (In most instances, this can be attained by switching the controller to the "off" position);

- measure and record the time required for the heat transfer fluid to drainback to the solar storage tank;

  Time for drainback _____ min

- the drainback time interval will begin when the pump is shut off and will terminate when the heat transfer fluid is restored to its original level in the solar storage tank site glass;

- complete drainback of the heat transfer fluid should occur in five minutes or less.

2.1.5 Motor and Pump Test

Preparations - Motor

- single phase motors need not be checked; however, all three phase motors should be checked for proper direction of rotation;
- verify that the motor is fully wired, protected, and ready to operate.

Preparations - Pump

- a time delay device should be attached to three phase pumps used in drainback systems. The time delay switch should prevent power being applied to the pump for an interval of at least the observed drainback time. This is to prevent damage that can occur to a three phase motor, if it is started up while running backwards;
- assure that all valves are in the position required for normal system operation;
- collect the applicable pump curves.

Responsibilities

- the test shall be the responsibility of the contractor;
- all testing will be witnessed by the owner or his appointed representative and by the design consultant.

Scheduling

- the rotation test will be performed following the installation and wiring of the motor and the pump.

- perform the circulation test as soon as the system is filled with liquid.

Direction of Rotation

- with the motor running, observe the end of the pump shaft to verify that it is running in the proper direction;

- if the pump is running backwards, connect the wires in the correct phase sequence.

Motor - Amperage

- with the motor operating, measure the current:

  Measured current _____

- the current should not exceed eighty percent of the nameplate rating.

Pump - Circulation Test

For each pump in the solar system, repeat this procedure:

- close the pump outlet valve;

- observe the pressures P_{in} and P_{out}. (See Figure 2.1.) The pressure difference across the pump ($P_{out} - P_{in}$) should be the maximum operating pressure for the pump, as specified by the manufacturer, or the zero flow rate pressure from the pump curve.

Pump No. _____	P_{in}	_____ kPa
Outlet valve closed	P_{out}	_____ kPa
	$P_{out} - P_{in}$	_____ kPa

- slowly, open the pump outlet valve;

- observe the output operating pressure P_{out}. The pump's output pressure should drop and remain at a pressure below the pump's stagnation pressure (P_{out} outlet valve closed). A drop in pressure and then a rise back to the stagnation pressure indicates a blockage in the system.

Outlet valve open	P_{out}	_____ kPa

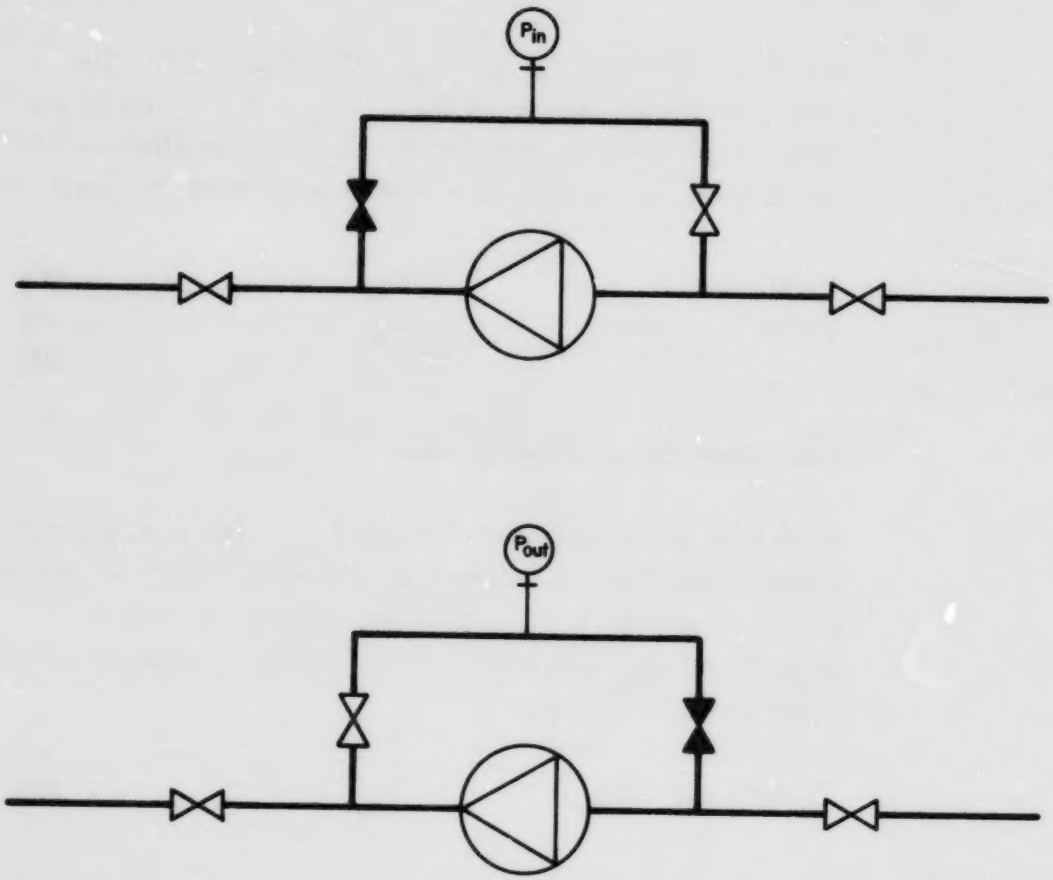


FIGURE 2-1
Pump Pressures

2.1.6 Leak Test

- the system should be pressure tested with the working fluid if possible;

- if conditions do not allow the use of the working fluid, an air or dry nitrogen test may be used;

- every liquid loop system shall hold for fifteen minutes;

  (a) without leakage, a water (glycol) pressure at least equal to the maximum pressure to which it may be subjected in service, or

  (b) without a drop in pressure, an air pressure of not less than 700 kPa or the maximum working pressure of the lowest rated component;

- all leaks should be noted and repaired immediately;

- the system should be retested following any repairs to the system.

2.1.7 Final Visual Inspection

- check the collector for outgassing:

    - in many instances, condensation forms on the underside of the glazing; however, this should "bake" off after one or two sunny days;

- if the condensation fails to bake off, then the condensation could be the by-product of the gases given off by the collector. In this case, the inside of the collector glazing will have to be cleaned or the glazing will have to be replaced;

- if condensation has fallen onto the absorber surface, an iridescent effect may appear. This will not effect the collector's performance if it is merely the condensate of water; however, if it is from outgassing, the oil residue will have to be removed from the absorber surface to restore the collector's performance. Before attempting to clean the absorber surface, contact the manufacturer of the collector for advice;

- for closed loop systems, verify that the system is completely filled with fluid. This check can be carried out by manually venting the air bleed valve at the high point in the system to ensure that no air is present;

- with the pump operating, verify the system flow by observing the flow indicator on the collector loop;

- verify that the system static pressure is within the tolerances of the given design and that this pressure does not exceed the rated pressure of the expansion tank;

Specified static pressure _____ kPa minimum
_____ kPa maximum

- verify that all manually operated valves are in the specified position (open or closed) required for normal operation of the system and that they have tags indicating the specified position;

- verify that the heat transfer fluid fill valve is sealed with a dated crimped seal.

2.1.8 System Flow Checks

Preliminary Information

- total collector loop flow required: [redacted] L/min
- obtain a copy of the manufacturer's pump curve for all pumps;
- if the collector loop has more than one circulation pump, the total flow through each pump will be as follows:

Pumps in Series

The flow through each pump will equal the total flow.

Pumps in Parallel

The sum of the flows through parallel pumps will equal the total flow.

Collector Loop Flow Rate

- if the system is provided with a proportional flow control system, it must be set to the maximum flow position;
- make sure the system is in an operating mode, with either the:
  - controller in the automatic position on a sunny day,
    or
  - controller in the manual position on an overcast day.
- if the collector loop has more than one pump for use during normal operation, make sure all the pumps are operating;
- check the flow indicator to verify that there is flow and that it is in the prescribed direction;

- the following test should be carried out for the pump or pumps in the collector loop;

  - measure the pressure differential across the pump(s);

    Measured pressure differential _____ kPa

  - from the manufacturer's pump curve, determine the operating point for the pump;

  - for this operating point, read off the operating flow rate;

    Flow rate as determined from pump curve _____ L/min

  - if pumps are in parallel, sum the individual flow rates to determine the total system flow rate;

  - adjust the flow by the means provided in the system until the flow rate is approximately equal to the specified flow rate;

  - record the final operating flow rate:

    Final operating flow rate _____ L/min

Collector Bank Flow Verification

- on a sunny day, with the circulation system operating and all balancing valves open, verify that flow exists in all banks. This may be accomplished by observing and recording the collector supply temperature and the bank outlet temperature for each bank of collectors:

collector supply temperature		_____ °C
bank number _____	outlet temperature	_____ °C
_____		_____ °C
_____		_____ °C
_____		_____ °C
_____		_____ °C

- if any of the bank outlet temperatures are significantly different from any others, there may be a restriction in the circuit.

2.2 MENU FOR PRODUCING A COMMISSIONING DOCUMENT

2.2.1 General Introduction to Commissioning Document

- Pre-conditions
- Responsibilities
- Scheduling

2.2.2 Verification of Pump Performance and System Flow Rates

- Collector Loop Flow Rate
- Bank Flow Rates

2.2.3 Final Flow Adjustment

2.2.4 Heat Exchanger Effectiveness

- Parallel Flow
- Counter Flow
- Cross Flow
- Coil-in-Tank or Wrap-Around

2.2.5 Preliminary Thermal Performance Test

Note: Italics are used to indicate direct instructions to the system designer.

2.2.1 General Introduction to Commissioning Document

Commissioning is a demonstration by the consultant and the contractor to the owner that the solar system is operating in a safe and efficient manner. The solar system will undergo a series of tests and adjustments to meet or exceed a prescribed level of efficiency.

Pre-conditions

- it is assumed that start-up has been successfully completed;

Responsibilities

- the commissioning will be carried out by the consultant and the contractor in the presence of the owner or his representative.

Scheduling

- the system must have been in operation for a minimum of five days after the final start-up test before the system is commissioned.

2.2.2 Verification of Pump Performance and System Flow Rates

Collector Loop Flow Rate

- if the system is provided with a proportional flow control system, it must be set to the maximum flow position;

- make sure the system is in an operating mode, with either the:

  - controller in the automatic position on a sunny day,
    or
  - controller in the manual position on an overcast day.

- if the collector loop has more than one pump for use during normal operation, make sure all the pumps are operating;

- check the flow indicator to verify that there is flow and that it is in the prescribed direction;

- the following test should be carried out for the pump or pumps on the collector loop:

  - measure the operating amperage of the pump(s) with a clamp-on ammeter;

    Measured amperage _____

  - convert amperage to the equivalent horsepower; using the equation on the following page;

    Calculated horsepower _____

Single Phase

$$P = E\ I \cos \varphi$$

Three Phase

$$P = \sqrt{3}\ E\ I \cos \varphi$$

where:

I = line current, amps
P = power, kW
E = line voltage, volts
cos φ = power factor

	Power Factor, cos φ	
	single phase	three phase
1/2 HP or less	.75	.75
1 - 2 HP	-	.75
2 1/2 - 15 HP	-	.80

1 HP = .7457 kW

- measure the pressure differential across the pump(s);

  Measured pressure differential _____ kPa

- from the manufacturer's pump curve, determine the operating point for the pump(s);

- for this operating point, read off the operating flow rate;

  Flow rate as determined from pump curve _____ L/min

- if pumps are in parallel, sum the individual flow rates to determine the total system flow rate;

- if the flow rate is not within twenty percent (plus or minus) of the specified flow rate, adjust the flow by the means provided in the system until the flow rate is within the allowable range, and record the new flow settings;

  Final operating flow rate _____ L/min

Bank Flow Rates

- with the system operating, measure the temperature rise across each collector bank;

bank number	temperature rise
_____	_____ °C
_____	_____ °C
_____	_____ °C
_____	_____ °C
_____	_____ °C

- if the temperature rise across the hottest bank is less than fifty percent greater than the temperature rise across the coldest bank, or within 1°C, and place a dated locking tag on all throttling valves;

- if the temperature rises are not within these limits, carry out the balancing procedures outlined below:

Balancing Procedures

- leave the balancing valve of the bank registering the highest temperature fully open - reduce the flow through the other banks by partially and judiciously closing the other balancing valves;

- leave the system to stabilize for about ten minutes and observe the bank outlet temperatures;

- repeat this process until the temperature rise across the hottest bank is less than fifty percent greater than the temperature rise across the coldest bank, or within 1°C, and place a dated locking tag on all throttling valves.

2.2.3 Final Flow Adjustment

- with the collector flows balanced, a final adjustment of the overall flow rate is made and the value is recorded;

- place a dated locking tag on the system throttling valve;

Note: A final flow adjustment is mandatory whenever the collector bank flows are altered.

Record the following:

Test Date: Time: Hours:

Total Collector Loop Flow _____ L/min

bank number	temperature rise
_____	_____ °C
_____	_____ °C
_____	_____ °C
_____	_____ °C
_____	_____ °C

2.2.4 Heat Exchanger Effectiveness

- the test should be carried out using the normal hot water draw on the load side;

- the design hot water draw rate is [redacted] L/min;

- record the hot water draw rate during the test, if possible: _____ L/min

- *determine the type of heat exchanger; parallel flow, counter flow, cross flow, coil-in-tank or wrap-around. Include a schematic of the heat exchanger that indicates where to measure the required temperatures. Edit the following instructions according to the heat exchanger type and flow characteristics:*

- with the pump(s) operating, measure and record the following temperatures;

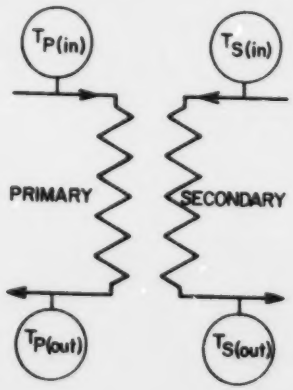
  - for parallel flow, counter flow or cross flow heat exchangers, measure:

$T_{P(in)}$ - primary side inlet _____ °C

$T_{P(out)}$ - primary side outlet _____ °C

$T_{S(in)}$ - secondary side inlet _____ °C

$T_{S(out)}$ - secondary side outlet _____ °C



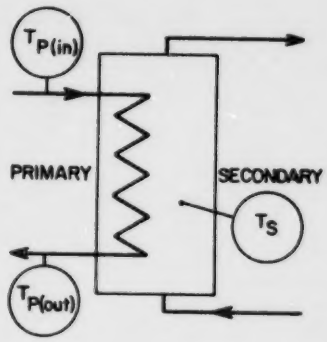
- for coil-in-tank or wrap-around, measure:

$T_{P(in)}$ - primary side inlet _____ °C

$T_{P(out)}$ - primary side outlet _____ °C

T_S - secondary side tank _____ °C

when coil is a section of the primary loop.

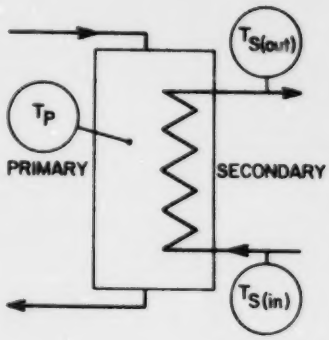


T_P - primary side tank _____ °C

$T_{S(in)}$ - secondary side inlet _____ °C

$T_{S(out)}$ - secondary side outlet _____ °C

when coil is a section of the secondary loop.



- calculate the heat exchanger effectiveness (E) using the correct equation from the following pages:

Heat exchanger effectiveness _____

A problem is indicated if the effectiveness is not within the following range: [redacted], [redacted].

Counter Flow, Parallel Flow and Cross Flow

- if $\dot{m}c_p$(minimum) is on the primary side:

  where: $\dot{m}$ is the mass flow rate (kg/sec),
  c_p is the specific heat of the fluid (J/kg$^{\circ}$C),
  and, therefore,
  $\dot{m}c_p$ is the heat capacity rate.

$$E = \frac{T_{P(in)} - T_{P(out)}}{T_{P(in)} - T_{S(in)}}$$

- if $\dot{m}c_p$(minimum) is on the secondary side:

$$E = \frac{T_{S(out)} - T_{S(in)}}{T_{P(in)} - T_{S(in)}}$$

- if $\dot{m}c_p$(minimum) cannot be determined, use the larger of the above two quantities.

Coil-in-Tank or Wrap-around

- if coil is a section of secondary loop:

$$E = \frac{T_{S(out)} - T_{S(in)}}{T_P - T_{S(in)}}$$

- if coil is a section of primary loop:

$$E = \frac{T_{P(in)} - T_{P(out)}}{T_{P(in)} - T_S}$$

2.2.5 Preliminary Thermal Performance Test

The preliminary thermal performance test is undertaken in order to assess the operation of the solar system as a whole, and to compare the results with the performance that should be expected based on the collector manufacturer's claimed performance.

Perform the thermal performance test on a sunny day between 11:00 a.m. and 1:00 p.m. The storage temperature must be well below the maximum.

- Record the following measurements:

T_A	- outdoor ambient temperature	_____ ^oC
$T_{C(out)}$	- collector return temperature	_____ ^oC*
$T_{C(in)}$	- collector supply temperature	_____ ^oC
F_S	- total collector loop flow rate	_____ L/min
I	- solar insolation	_____ W/m^{2**}

*The collector return temperature should be measured at the return header on drainback systems. This will ensure that the temperature is indicative of the heat transfer fluid and not a fluid/air mixture.

**The solar insolation should be measured using a hand held pyranometer. Measure the insolation during the test period. Hold the pyranometer against the surface of the collector when taking measurements.

Airport weather stations may be able to supply current solar insolation levels.

- determine the density and the specific heat of the collector heat transfer fluid:

  where: c_p is the specific heat in J/kg°C

  $$= \frac{\%\ \text{water} \times 1\ \text{kg/L} + \%\ \text{glycol} \times c_p\ \text{glycol}}{100} = _____\ \text{kg/L}$$

  $$= \frac{\%\ \text{water} \times 4190\ \text{J/kg°C} \times \%\ \text{glycol} \times c_p\ \text{glycol}}{100} = _____\ \text{J/kg°C}$$

- calculate the temperature rise across the collector:

  $$\Delta T = T_{C(out)} - T_{C(in)} = _____\ ^{o}C$$

- determine the heat gain:

  where: ρ is the density in kg/L

  $$Q = \frac{F_S \times \rho \times \Delta T \times c_p}{60} = _____\ W$$

  $$\frac{L}{min} \times \frac{kg}{L} \times \frac{min}{s} \times {}^{o}C \times \frac{J}{kg\ {}^{o}C} \times \frac{W}{J/s}$$

- determine the heat gain per unit of collector area:

  $$q = Q/A$$
  $$= _____\ W/m^2$$

- the efficiency is then:

$$\frac{q}{I} \times 100 = _____ \%$$

- determine the manufacturer's claimed efficiency, for the given conditions, for:

  (a) Parallel Operation

$$\text{Operating point} = \frac{T_{C(in)} - T_A}{I}$$

  (b) Series Operation

$$T_{reference} = \left[\frac{(N - 1)}{2N} (T_{C(out)} - T_{C(in)}) \right] + (T_{C(in)})$$

  Where N = number of collectors in series

$$\text{Operating point} = \frac{T_{reference} - T_A}{I}$$

- read the efficiency from the manufacturer's performance curve for this operating point.

Since the measured efficiency includes line losses, it can be expected to be slightly lower than the claimed efficiency for the collectors alone. However, the measured efficiency should not be more than twenty percent lower than the predicted value.

3.0 OPERATIONAL MONITORING

This section provides a framework and methodology for the development of an operator's handbook for any specific solar system design.

Before the system operator can be expected to successfully perform the operational monitoring of a solar heating system, he must be made familiar with the general concepts and specific operation of the system. These tasks are accomplished in introductory sections to the operator's manual.

The approach taken in the development of operational monitoring procedures is to define key information for each system to ensure that:

- the system is working,
- durability is not degraded, and
- efficiency remains near design and commissioning values.

While a specific solar system does not have a standard performance range, components of the system have performance ranges that are defined by the design specifications. The design specifications are verified by tests during the commissioning procedure and the resulting verified values become the standard performance values of the various components.

The next step is to define the:

- daily,
- monthly, and
- and semi-annual

operational maintenance schedules. Judgement is needed to determine which readings should be included in each of the three schedules. Note that the objective is to detect operating problems or a decrease in the performance of the system while efficiently utilizing the operator's time.

A requirement of this section is to educate the operator to check important system characteristics against their acceptable range.

For each instrument reading, the operator must be supplied with the performance range or tolerance variation which is derived from the original design specifications and verified in the start-up and commissioning procedures. This will give him the necessary background knowledge to detect operational problems.

Daily Inspections

Items that should be checked visually on a daily basis are those that would indicate a system malfunction of an immediate nature. These are typically:

- system pressures,
- pump operation in relation to weather and control modes,
- system temperatures in relation to control modes,
- status of system alarms,
- evidence of leaks or pressure relief valve activation.

Monthly Checks

Primarily, monthly checks will entail a more detailed examination of items that are checked daily. Recording this information will provide an historical record of the system's performance. Verification of the operation of the controls in relation to system design modes, the weather and system temperatures would be an example of a possible monthly check.

Semi-Annual Checks

Each spring and fall a detailed examination of the system will be performed. Many of the tests required in the start-up and commissioning phase will be repeated. Some typical semi-annual checks and tests include:

- fluid quality checks
- control system checks for:
    - sensor mountings security
    - calibration of sensors
- check the condition of filters and strainers
- testing of valves to assure functioning
- inspect fluid level in expansion tank
- heat exchanger effectiveness test

3.1 MENU FOR PRODUCING AN OPERATOR'S MANUAL

3.1.1 General System Description

3.1.2 System Operation

3.1.3 Introduction to Operational Monitoring

3.1.4 Operational Monitoring Procedures

- Daily Operational Checklist
  - Pumps
  - System Pressures
  - System Temperatures
  - Fluid Level (Drainback Systems only)
  - General Overview
- Monthly Operational Schedule
- Semi-Annual Operational Maintenance Schedule
  - Fluid Quality - Closed Loop Glycol System
  - Fluid Quality - Drainback System
  - Heat Exchanger Effectiveness
  - Sensor Calibration Check
  - Preventative Maintenance

Note: Italics are used to indicate direct instructions to the system designer.

3.1.1 General System Description

This section should include an explanation of the purposes for the solar system and the benefits it is likely to yield.

The general description of the solar system should include the basic system layout with a complete schematic diagram, as well as its basic principles of operation suitable for a person unfamiliar with solar technology.

3.1.2 System Operation

Included here should be explanations of the various modes of operation of the system with a detailed description of the system operation in each mode. These descriptions should go into enough depth that the function of all operating components of the system will be clearly understood. Particular emphasis should be placed on the operation of the control system. Include a system diagram indicating the location of all operational monitoring equipment and test points.

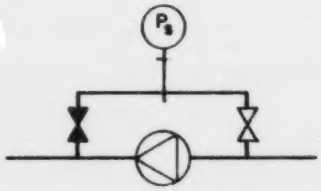
For each instrument, include a description of what it is measuring and an outline of the procedure to get the desired measurement. This will give the operator the necessary background to perform the monitoring tests. The following description can be edited to apply to any particular solar system.

In order to follow the operational monitoring schedule, the following measurements must be understood:

- number of cycles: During the course of a day, the solar system is turned on (pumps on) by the control system when sufficient solar energy is available. When the amount of energy drops to the point where operating the system is no longer practical, the controller turns off (pumps off)

the solar system. Every time the controller turns the system on or off, an "event" is counted on the "event counter". It is important that the controller turns the pumps on and off at the appropriate conditions and, therefore, does not cause the system to cycle excessively. To verify that the controller is working properly, the "number of events" for a period are checked.

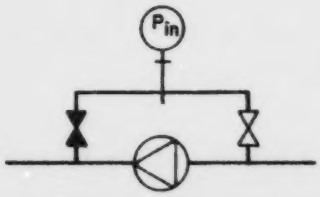
- system static pressure:



PUMPS OFF

The static pressure is the pressure of the liquid in the piping system with the pumps off. The static pressure will be measured in both the primary loop (glycol) and the secondary loop (water). The procedure is the same for both cases. With the pumps off and the valve just down stream from the pressure gauge closed, the pressure gauge measures the static pressure.

- inlet pump pressure:

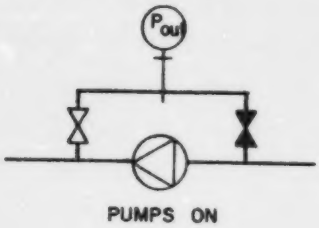


PUMPS ON

The inlet pressure is the pressure of the liquid in the piping system just upstream of the pump when it is operating.

The inlet pressure will be measured in both the primary glycol loop and the secondary water loop. The procedure is the same for both cases. With the pumps on and the valve just downstream from the pressure gauge closed, measure the inlet pressure.

- outlet pump pressure:



The outlet pressure is the pressure of the liquid in the piping system just downstream of the pump when it is operating.

The outlet pressure will be measured in both the primary glycol loop and the secondary water loop. The procedure is the same for both cases. With the pumps on and the gate just upstream from the pressure gauge closed, the pressure gauge measures the outlet pressure.

- pump run time:

The run time meter attached to each pump clocks the time the pump is operating. This information is used to ensure that the system is operating close to the expected amount of time.

- temperatures:

There are several permanently installed temperature probes with a digital readout:

- temperature of glycol/water mixture after it has been heated by the collectors,

- temperature of glycol/water mixture before it has been heated by the collectors,

- temperature of the glycol/water mixture before entering heat exchanger,

- temperature of the glycol/water mixture after leaving the heat exchanger,

- temperature of glycol/water mixture in drainback tank,

- temperature of water in the secondary loop before entering the heat exchanger,

- temperature of water in the secondary loop after leaving the heat exchanger,

- temperature of water in the secondary loop tank (coil-in-tank or wrap-around heat exchangers).

- system alarms:

The high limit thermostat sets off an alarm if the temperature of the fluid leaving the collector is too high.

3.1.3 Introduction to Operational Monitoring

The prime purpose of operational monitoring is to detect a decrease in the solar system performance. This is done by regularly comparing certain indicators, such as temperatures, pressures and pump run times with those specified in the design and commissioning process. A change in these indicators to outside the design range means that the system has an operational problem. Identifying operational problems or system breakdowns as soon as possible is important in reducing damage to the system, and will also maximize the energy output of the solar system. Early detection of problems will also increase the life of the system, and keep operating and maintenance costs to a minimum.

Checks of instrument readings and verifications of the operation or condition of component equipment are conducted on a set of schedules as follows:

- daily,
- monthly, and
- semi-annually or yearly.

3.1.4 Operational Monitoring Procedures

Daily Operational Checklist

To ensure that no major malfunction of the solar system has occurred, the following questions should be considered daily. If the answer to any of the questions is "no", a problem has been detected. To determine the cause of the problem and the required action, see the Operator's Troubleshooting Guide.

Pumps

1. If the weather is sunny, or partially sunny, are the pumps operating?

2. If there is no sun, are the pumps off?
3. If the pumps are operating, is the period of operation reasonable? A problem is indicated if the event counter indicates more than [redacted] cycles per day.

System Pressures

4. Is the system static pressure within the acceptable range? (acceptable range: [redacted] kPa to [redacted] kPa)
5. If the pumps are operating, is the change in pressure across each pump in the specified range? (low, high) (acceptable range: [redacted] kPa to [redacted] kPa)
6. If the pumps are operating, is the discharge pressure relatively constant for each pump? (maximum deviation = [redacted] kPa)

System Temperatures

7. If the pumps are operating, is the rise in temperature between "storage to collector" and "collector to storage" within the specified range? (acceptable rise in temperature: [redacted] °C to [redacted] °C).

Fluid Level (Drainback Systems Only)

8. If the system is not operating, is the fluid level in the draindown tank within the acceptable range? (acceptable level range within [redacted] cm of marked line)

General Overview

9. Does the status of all system alarms indicate normal system operation?
10. Have the pressure relief valves remained closed?
11. Are the vibration and noise levels normal?
12. Is the temperature of all mechanical equipment normal? (no overheating)

Monthly Operational Schedule

Every month a more detailed version of the "daily checks" will be performed and recorded in the chart shown in Figure 3.1. This procedure will provide an historical record of the solar system's performance as well as a closer examination of the system to check for possible problems. The monthly checks should be done on a day when solar energy is available and the system is cycling. Use the following procedure to obtain the values for the chart.

(a) Fill in general information; name, date, time, weather description and outside temperature.

(b) For each pump module:

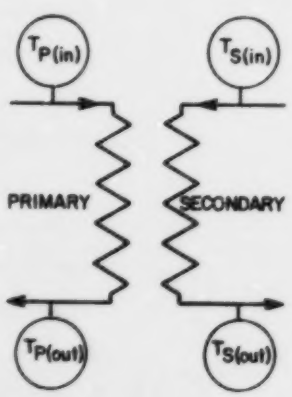
Read and record the pump run time. Subtract the previous month's reading to find the monthly pump run time. Compare this with the expected value for the month. Being high or low may be a result of abnormal weather, but may also be an indication of problems.

Read and record the system static pressure (P_S), the pump discharge pressure (P_{out}), and the pump suction pressure (P_{in}).

Calculate and record the pressure difference across the pump ($P_{out} - P_{in}$).

(c) Read and record the following temperatures:

- Primary circuit heat exchanger: in — $T_{P(in)}$
- Primary circuit collector: feed — $T_{P(out)}$
- Secondary circuit heat exchanger: in — $T_{S(in)}$
- Secondary circuit heat exchanger: out — $T_{S(out)}$
- Solar storage tank: top, bottom



Calculate ($T_{P(in)} - T_{P(out)}$) and ($T_{S(out)} - T_{S(in)}$). Record.

MONTHLY OPERATIONAL RECORD

OPERATOR	MONTH	DAY	TIME	WEATHER		PUMP MODULE NO.1							PUMP MODULE NO.2							TEMPERATURES (°C)								TEMPERATURES (°C)								Control Module		Drain Down System	
						Run Time (hrs)			Pressure (kPa)				Run Time (hrs)			Pressure (kPa)				Heat Exchanger No. 1						Solar Storage Tank		Heat Exchanger No. 2						Solar Storage Tank					
				CLEAR, VARIABLE, or OVERCAST	OUTDOOR TEMP (°C)	TOTAL	MONTHLY	EXPECTED	P_S	P_{out}	P_{in}	$P_{out} - P_{in}$	TOTAL	MONTHLY	EXPECTED	P_S	P_{out}	P_{in}	$P_{out} - P_{in}$	PRIMARY In $T_{P(in)}$	PRIMARY Out $T_{P(out)}$	SECONDARY In $T_{S(in)}$	SECONDARY Out $T_{S(out)}$	$T_{P(in)} - T_{P(out)}$	$T_{S(out)} - T_{S(in)}$	TOP	BOTTOM	PRIMARY In $T_{P(in)}$	PRIMARY Out $T_{P(out)}$	SECONDARY In $T_{S(in)}$	SECONDARY Out $T_{S(out)}$	$T_{P(in)} - T_{P(out)}$	$T_{S(out)} - T_{S(in)}$	TOP	BOTTOM	EVENTS TO DATE	EVENTS FOR MONTH	TIME TO DRAIN (min)	LEVEL (from top)
	Jan.																																				
	Feb.																																				
	Mar.																																				
	Apr.																																				
	May																																				
	June																																				
	July																																				
	Aug.																																				
	Sept.																																				
	Oct.																																				
	Nov.																																				
	Dec.																																				

SYSTEM FAILURE REPORT

OPERATOR	DATE	DESCRIPTION

FIGURE 3-1

(d) For each control system module, read and record the number of events to date. Calculate the number of events for the month and compare it to the acceptable range.

(e) Additional checks for draindown system:

Manually stop the pump and record the time taken for the fluid to completely drain. Measure and record the fluid level.

(f) Analysis of monthly record:
Compare all readings and calculated values to their specified ranges. If they are outside of the range, consult the Operator's Troubleshooting Guide.

(g) The following preventative maintenance checks should also be performed:

- clean collector glazing where necessary,
- inspect collectors for the following:
    - weep holes full of debris, insects, ice, etc.,
    - deterioration of the absorber plate in the form of discolouration or buckling,
    - permanent condensation on the underside of the collector glazing,
    - temperature variance: a collector that is noticeably cooler or warmer than the others indicates a flow blockage or imbalance (a heat meter reading of the collector surface temperature will do),
- check mounting hardware security and caulking as well as flashing around roof penetrations,
- lubricate pumps, motors and control linkages as required.

Semi-Annual Operational Maintenance Schedule

Semi-annual checks will be conducted each spring and fall. The schedule includes several repeats of test procedures that were done as part of the start-up and commissioning, along with preventative maintenance checks.

Fluid Quality - Closed Loop Glycol System

Three characteristics of the glycol need to be checked semi-annually. If the facilities are not available "in-house", send a sample of glycol to an analysis lab.

1. Determine the percentage of glycol to water using a hydrometer, refractometer, or by the ASTM E 203 - 75 - Water using Karl Fischer Reagent. The percentage of glycol determines the freeze point of the solution. The percentage of glycol must be greater than [illegible] % and less than [illegible] %. If it is out of the acceptable range, alter it.

2. Determine the pH factor (a measure of the acidity of the solution) in accordance with the ASTM D 1613 - 66 (Reapproved 1972). In order to minimize corrosion, the pH of the solution must be greater than [illegible] and less than [illegible].

3. Determine the reserve alkalinity (a measure of the amount of inhibitor available to react with and neutralize acids formed in the glycol) in accordance with ASTM D 1121-72 Reserve Alkalinity of Engine Antifreeze, Antirusts and Coolants. If the reserve alkalinity is not within the range [illegible] to [illegible], restore it to the required level by using the manufacturer's method.

Fluid Quality - Drainback System

To control the entry of corrosion causing oxygen into the water of the collector loop, some drainback systems use an oil film on the top of the water in the drainback tank. If this is used, check the oil film thickness and replenish, if necessary.

If alternate corrosion inhibitors are utilized, check them according to the manufacturer's recommendation.

Heat Exchanger Effectiveness

The test should be carried out using the design hot water draw on the load side.

The design hot water draw is _____ L/min.

Determine the type of heat exchanger; parallel flow, counter flow, cross flow, coil-in-tank or wrap-around. Include a schematic of the heat exchanger that indicates where to measure the required temperatures. Edit the following instructions according to the heat exchanger type and flow characteristics:

With the pump(s) operating, measure and record the following temperatures;

For parallel flow, counter flow or cross flow heat exchangers, measure:

$T_{P(in)}$ - primary side inlet _____ ^{o}C

$T_{P(out)}$ - primary side outlet _____ ^{o}C

$T_{S(in)}$ - secondary side inlet _____ ^{o}C

$T_{S(out)}$ - secondary side outlet _____ ^{o}C

For coil-in-tank or wrap-around, measure:

$T_{P(in)}$ - primary side inlet _____ °C

$T_{P(out)}$ - primary side outlet _____ °C

T_S - secondary side tank _____ °C

when coil is a section of the primary loop.

T_P - primary side tank _____ °C

$T_{S(in)}$ - secondary side inlet _____ °C

$T_{S(out)}$ - secondary side outlet _____ °C

when coil is a section of the secondary loop.

Calculate the heat exchanger effectiveness (E) using the correct equation from the following pages:

Heat exchanger effectiveness _____

A problem is indicated if the effectiveness is not within the following range: [illegible], [illegible].

Counter Flow, Parallel Flow and Cross Flow

- if $\dot{m}c_p$(minimum) is on the primary side:

  where: $\dot{m}$ is the mass flow rate (kg/sec),
  c_p is the specific heat of the fluid (J/kg^{o}C),
  and, therefore,
  $\dot{m}c_p$ is the heat capacity rate

$$E = \frac{T_{P(in)} - T_{P(out)}}{T_{P(in)} - T_{S(in)}}$$

- if $\dot{m}c_p$(minimum) is on the secondary side:

$$E = \frac{T_{S(out)} - T_{S(in)}}{T_{P(in)} - T_{S(in)}}$$

- if $\dot{m}c_p$(minimum) cannot be determined, use the larger of the above two quantities.

Coil-in-Tank or Wrap-around

- if coil is a section of secondary loop:

$$E = \frac{T_{S(out)} - T_{S(in)}}{T_P - T_{S(in)}}$$

- if coil is a section of primary loop:

$$E = \frac{T_{P(in)} - T_{P(out)}}{T_{P(in)} - T_S}$$

Sensor Calibration Check

Sensor accuracy can change with time due to the build up of corrosion at the attachment points or the lead connections. Sensor accuracy can also be distorted when it experiences temperature extremes that exceed its design range. Since combined inaccuracies in both the collector and storage sensor inputs can significantly reduce the system performance, sensor calibration checks should be performed semi-annually.

A total of four tests are required:

1. collector sensor at cool temperature (early in morning on cloudy day),
2. collector sensor at hot temperature (mid to late afternoon on sunny day),
3. storage tank sensor at cool temperature,
4. storage tank sensor at hot temperature.

For each test, measure the temperature at the point and the resistance at the control connection. Compare the readings to the temperature-resistance curve supplied by the manufacturer. If there is a discrepancy, corrosion or extreme temperatures could have damaged the sensor or its connections. Check both and replace, if necessary, then repeat the test.

Preventative Maintenance

- Clean filters and strainers
- Cycle or operate valves to assure functioning
- Oil or lubricate components according to the manufacturer's recommendations
- Check charge on expansion tank

4.0 TROUBLESHOOTING

Troubleshooting involves the diagnosis and correction of system operational problems or malfunctions. The procedures outlined in this section are designed to:

- assist the operator of the system in solving simple problems detected by the operational monitoring procedures, and

- assist a technician in troubleshooting more extensive or difficult problems.

System problems should be initially identified by the system operator through his operational monitoring schedule. The Troubleshooting Guide should be based on observations stemming directly from these procedures.

When a system problem has been identified and is not corrected by the most obvious solutions, a troubleshooting engineer or technician must take a closer look at the problem.

The chart should be accompanied by an outline of procedures for problem isolation and correction which can assume the use of portable instrumentation using the monitoring point provisions included in the solar heating system design. The procedures can also assume that the person carrying out the test has a reasonable background in the troubleshooting of solar heating systems.

The suggested format is a chart organized on a component basis with separate sections for complex problems such as solving control system problems and a general deterioration of performance.

Sections 4.1 contains a general troubleshooting guide. The designer of a solar system may use this guide as a basis for his troubleshooting manuals by deleting those procedures not relevant to his particular design and modifying the others to suit the particular application. Troubleshooting of control system problems are detailed in Section 4.2, while Section 4.3 deals with diagnostic procedures for cases where the fault can not be traced to a single component.

4.1 TROUBLESHOOTING GUIDE

Symptom	Source	Cause	Action
No hot water or heat	Make-up water shut-off valve	Valve closed	Open valve.
	Auxiliary heater	Failed to activate	Check breaker or fuse. Check power to heater. Check fuel supply.
Hot water temperature too low	Hot water thermostat	Thermostat setting too low	Set thermostat higher.
	Auxiliary heater	Not functioning	Check breaker or fuse. Check and repair auxiliary heating unit and fuel supply.
	Temperature modulating valve	Faulty	Repair or replace.
		Temperature set too low	Reset.
Water temperature too high	Hot water thermostat	Thermostat setting too high	Reset.
		Thermostat out of calibration	Recalibrate.
	Temperature modulating valve	Faulty	Repair or replace.
		Temperature set too high	Reset.
Insufficient hot water to load, but solar system seems normal	Auxiliary heater	Auxiliary heater problems	Check auxiliary heater, wiring, gas, oil lines, burners, and set points.
	Valves	Isolation valves improperly closed	Set in proper positions.
	Temperature modulating valve	Improperly adjusted	Check adjustment. Adjust as necessary.
		Faulty	Repair or replace.

Symptom	Source	Cause	Action
Insufficient heat but solar system seems normal	Auxiliary heater	Auxiliary heater problems	Check auxiliary heater, wiring, gas, oil lines, burners, and set points.
	Valves	Isolation valves improperly closed	Set in proper positions.
Drop in water pressure at both hot and cold outlets	Inlet water pressure	Inlet strainer clogged	Clean basket.
	Pressure reducing valve	Malfunctioning	Check for plugged ports, and proper operation. Clean, repair, or replace.
Drop in water pressure at hot outlets only	Valves	Valve improperly closed	Open manual valves Check automatic valve operation, repair or replace.
		Jammed check valve	Repair and replace.
	Strainers	Flow restriction	Check and clean.
System does not start or Pump(s) not running when solar energy available	Power supply	Control switch on "off" position	Turn to "auto" position.
		No power to pump	Check fuses or circuit breaker.
			Check wiring and connections.
		No power to controller	Check fuses or circuit breaker.
			Check wiring and connections.
	Pump	Pump seized	Try turning by hand. Repair or replace.
		Motor failure	Repair or replace.
	Controls	Control failure	Try on "manual". If pump runs, suspect control system. (Refer to Troubleshooting Controls)
		Pressure cut offs activated	Rectify cause, reset.
		Temperature cut off activated	If tank temperature below high limit cut off, check control system. (Refer to Troubleshooting Controls)

Symptom	Source	Cause	Action
		Fault in control system	Check control system. (Refer to Troubleshooting Controls)
		Electrical problem	Check line terminal voltage.
Pump(s) running when no solar energy available	Control system	Control set on "manual"	Set on "automatic".
		Fault in control system	Check control system. (Refer to Troubleshooting Controls)
Pump cycling excessively	Controls	Incorrect set points	Check set point.
		Fault in control system	Check control system. (Refer to Troubleshooting Controls)
System static pressure low	Charge pressure low	Fluid level low	See "Fluid level low".
	Expansion tank (Diaphram)	Bladder capacity exceeded or diaphram leaking	Inspect for fluid in air chamber, replace expansion tank.
	Expansion tank (Standard)	Inadequate air space	Adjust liquid level.
		Air leak	Find and correct.
Fluid level low	Leak in system	Piping leak	Repair. Replace wet insulation.
		Leak from drain	Close drain tightly, add cap.
		Leak from air vent	Inspect, clean mechanism, repair or replace.
	Pressure relief valve	Relief valve has expelled excess pressure	Find cause for excess pressure; correct. Recharge system to operating pressure.
System static Pressure high	Controls	Overtemperature	Find cause. (Refer to Troubleshooting Controls)

Symptom	Source	Cause	Action
	Fluid	System overfilled	Check level.
	Expansion tank	Expansion tank is waterlogged	Check expansion tank liquid level. Check for air leak.
Pump discharge pressure fluctuating	Pump	Cavitation	Find source of air entry, check for restriction on suction side, clean strainer.
System does not drain (Drain Systems)	Vacuum breaker	Damaged	Replace.
		Frozen	Thaw and protect from freezing.
	Piping	Piping not sloped adequately	Correct.
		Vent tube blocked	Check and clear.
	Controls	Control and sensor fault	(See "Troubleshooting Controls")
	Solenoid or motorized valve	Actuator defective	Replace.
		No power to actuator	Check wiring.
		Valve sticks	Repair or replace valve.
System will not fill with pump running (Drain systems)	Pump	Cavitation	Check for air entry, check for restriction on pump suction side, clean strainer.
			Check for low fluid level in drain back tank.
System drains continuously with pump running (Draindown Systems only)	Drain down valve will not close	Actuator defective	Replace.
		Power	Check wiring.
		Valve sticks	Repair or replace valve.
	Freeze protection thermal switch	Set point drift	Reset or replace.
		Defective	Replace.
		Loose contacts	Reconnect.
	Control sensors	Out of calibration	Recalibrate.
		Defective	Replace.

Symptom	Source	Cause	Action
Pressure does not drop when system filled (syphon type drain back systems)	Piping	Leak in pipes causes break in syphon	Find and seal.
		Major flow restriction in system	Check position of all valves.
	Vacuum breaker	Faulty	Replace.
		Frozen	Thaw and protect from freezing.
	Fluid	Leak has reduced fluid level	Seal leak; refill system.
	Pump	Impeller fouled or damaged to point that pump cannot overcome static head	Clean or repair pump.
Storage temperature decays during periods of no load	Insulation	Damaged or wet	Repair or replace.
	Check valve	Reverse thermosyphoning	Inspect check valve operation. Repair or replace.
Storage temp remains high during high load, little solar	Valves	Isolation valves improperly closed	Set in proper position.
Poor solar energy collection	Collector array	Film on collector glazing	Check for dirt on glazing. Check for condensation and outgassing. Clean glazing.
		New source of shading	Check for new structures growth of trees, etc.
		Flow rate	Check flow rate. Reset to specified flow.
			Check operation of automatic flow control valve. Repair or replace as necessary.
		Flow balance	Check balance of flow through collector banks. Rebalance as necessary.
			Check operation of automatic flow control valves. Repair or replace as necessary.

Symptom	Source	Cause	Action
		Scale forming in collector tubes	Flush collector loop.
	Piping	Insufficient or damaged insulation	Check condition and adequacy of insulation. Repair, replace or add additional insulation.
	Collector fluid	Antifreeze/water concentration in collector loop fluid is improper	Check fluid properties. Follow manufacturer's recommendations.
		Reverse thermosiphoning	Inspect check valve operation. Repair or replace.
	Controls	Out of calibration	(See "Troubleshooting Controls")
Excessive vibration or noise in system	Pump	Cavitation	Check for air entry, check for resriction on pump suction side, clean strainer.
		Bearings	Check for hot or worn bearings. Check bearing alignment.
		Impeller	Inspect for misaligned shaft, repair, replace.
			Check balance of impeller clean, repair or replace.
	Piping	Entrapped air	Check automatic air vents. Vent manually. Force purge system, find and correct source of air entry.
		Supports	Check condition and adequacy of hangers. Repair hangers or install additional hangers.
Water hammer	Automatic valves	Open or close too fast	Install valves with slower action. Modify controls to slow valve action.

The following section of the diagnostic chart will be helpful if either the pump operating pressures or the system ΔT as defined in the operator's manual are out of the specified range

Pump discharge pressure is not in the design range

If this condition is found carry out the following checks:

1. Check system static pressure and insure that it is in the proper range.
2. Using the pump inlet pressure and the pump discharge pressure, determine the pressure difference across the pump (ΔP).

Symptom	Source	Cause	Action
ΔP high		Generally the result of a flow restriction of some type	
	Valves	Flow control valves tampered with (closed)	Check seal on valves, if tampered with adjust flow as per commissioning procedure.
		Shut-off valves closed	Open.
		Automatic valves closed	Check controls, operation, and springs, repair or replace.
	Check valve	Jammed	Repair or replace.
	Air vents	Faulty - causing air lock	Operate needle valve manually; check float control, inspect, clean, repair or replace.
	Collector	Passages clogged	Feel if some collectors hotter than others. Remove collector, backflush passages.
	Strainer	Flow restriction	Check and clean strainers.
ΔP Low	Valves	Flow control valves tampered with (closed)	Check seal on valves, if tampered with adjust flow as per commissioning procedure.
	Three-way valves	Internal leaking	Check and repair.
	Pump	Cavitating	Find source of air entry. Check for flow resriction on suction side, clean strainer.
		Mechanical failure	Check and repair.

Symptom	Source	Cause	Action
ΔT low ΔP(s) normal	Collectors	Dirty	Clean surface.
		Insulation wet	Dry or replace insulation. Reseal collectors.
		Excessive condensation	Inspect seal, pipe gaskets, and weep holes. Repair.
	Pipe or tank insulation	Damaged, wet or missing	Repair or replace.
	Heat exchanger	Scaled up	Clean heat exchanger.
	Controls	Setting incorrect or drifting	Reset. (See "Troubleshooting Controls")
ΔT low ΔP(s) low	Flow control valves	Tampered with (opened)	Check seals on valves, if tampered with adjust flow as per commissioning procedure.
	Three-way valves	Internal leaking	Repair.
	Controls	Incorrectly set	(See "Troubleshooting Controls")
ΔT high ΔP(s) normal	Controls	Incorrectly set	(See "Troubleshooting Controls")
ΔT high ΔP(s) low	Pump	Cavitation	Find source of air entry, correct, clean strainer, check for restriction on suction side.
		Impeller damage	Check stagnation pressure. Repair.
	Three-way valves	Internal leak	Check and repair.

Symptom	Source	Cause	Action
ΔT high ΔP high		Generally the result of a flow restriction of some type	
	Valves	Flow control valves tampered with (closed)	Check seal on valves, if tampered with adjust flow as per commissioning procedure.
		Shut-off valves closed	Open.
		Automatic valves closed	Check controls, operation, and springs, repair or replace.
	Check valve	Jammed	Repair or replace.
	Air vents	Faulty -- causing air lock	Operate needle valve manually; check float control, inspect, clean, repair or replace.
	Collector	Passages clogged	Feel if some collectors hotter than others. Remove collector, backflush passages.
	Strainer	Flow restriction	Check and clean strainers.
Pump run time too high			(See "Pump(s) running when no solar energy available")
Pump run time too low			Check ΔT and ΔP(s) and refer to appropriate section, if cause not evident, refer to "System Diagnostic Procedures".

4.2 TROUBLESHOOTING SOLAR CONTROLS

In troubleshooting solar controls, it is important to use a logical and systematic approach in isolating and correcting system faults. The following is the recommended procedure. This procedure is for variable resistance type controllers. For I.C. controllers, which use variable voltage sensors, voltages are measured instead of resistances.

Differential Controller Checks

1. Check power supply to controller.

2. Check that all components are wired correctly to controller (according to manufacturer's specifications).

3. If the pump or valve does not work in the "manual" mode, disconnect it from the controller and apply rated voltage to its input wires at the controller.

    a. If it runs, the pump is all right - the problem is in the control system.

    b. No operation - the pump or valve is faulty or the interconnecting wiring or relay is faulty. Isolate the fault and repair or replace the defective component.

4. Check all sensors for:

    - proper location,
    - secure attachment with no corrosion build-up,
    - proper wiring to controller.

5. Check each sensor for proper resistance by disconnecting it at the controller. If the measured resistances are as specified,

the fault is a controller problem. Proceed to Step 8. If the measured resistances do not correspond to the specification value for the temperature of the sensor location, then:

- the sensor is faulty,
- the interconnecting wiring is faulty.

6. Disconnect sensor from wiring leading to the controller. Check the sensors resistance at this point. If the resistance is not to specification, replace the sensor.

7. If sensor is accurate, check for corrosion at all wiring connections. Clean, reconnect and remeasure resistance at the controller. If the measured resistance is still not correct, replace the wiring between the sensor and the controller.

8. Controller operational check.

   - switch off the electrical power t all pumps and/or control valves and make sure the controller is set for the recommended temperature differential;

   - replace the temperature sensors at the collector and the tank with variable resistors (variable resistors with readouts will simplify the procedure). The resistors can be connected to the sensor terminals at the controller;

   - from the temperature sensor characteristic curve, determine the resistance associated with 5°C absolute temperature;

   - dial this resistance into the variable resistor on the output to the tank sensor. Record the resistance;

- with the controller set in the automatic position, gradually change the resistance on the collector side until an output is measured at the controller output terminals (to pump or control valve). Record the indicated resistance;

- vary the resistance until there is no longer an output at the controller output terminals. Record the indicated resistance;

- reset the tank variable resistor for the resistance associated with a 15°C absolute temperature;

- repeat the above procedure determining the collector resistance to receive an output at the output terminal and the resistance to receive no output. Record both resistances;

- calculate the differential resistance, and from the temperature sensor characteristic curve determine the temperature differential;

- compare this with the original setting of differential temperature;

- if the two figures disagree substantially (more than ten percent), adjust the controller setting and repeat the above test.

9. Sensor Calibration Check

Preparation

1. Obtain a copy of the temperature sensor characteristic curve from the appropriate manufacturer (resistance vs. temperature).

2. Obtain a digital multimeter with an appropriate probe to determine as accurately as possible the temperature at the point the sensor is intended to sense.

Method

Determine the temperatures at the points the sensor is intended to sense. These will likely be the absorber plate in one of the collectors and the temperature in the lower third of the storage tank.

Measure with an ohm meter the resistance shown by the sensor. This should be done at two temperatures for each sensor, for example:

For collector sensors:

1. Cool Temperature - as early as possible in the morning, preferably on a cloudy day.

2. Hot Temperature - mid to late afternoon on a sunny day.

For storage tank sensors:

1. Cool Temperature - after a major draw of heat from storage to load on a cloudy day and before the auxiliary heat has replenished the draw (where applicable).

2. Hot Temperature - late on a sunny day before a major draw of heat or on a day when the load is reduced.

Compare the measured resistance with that shown on the manufacturer's table or graph for the appropriate temperature.

If the resistance varies from the expected value, the sensor or sensor lead connections may be corroded or the sensor may have been damaged by heat extremes. Check both and replace as necessary then repeat the test.

Freeze Protection Controls

Thermal switch sensors are used for freeze protection of the collector loop on drainback systems or the heat exchanger on closed loop systems.

The freeze protection set point should be at least 3°C (5°F) above the actual freezing point. Once the thermal switch set point is reached, the switch should de-activate the pump on drain back systems, causing the system to drain. In closed loop glycol systems, the freeze protection thermal switch circuit prevents the pump running in the event of a controller failure.

Sensors used for freeze protection may be either the thermal switch type or variable resistance type.

Test Procedure for Thermal Switch Type

1. Connect the thermal switch to an ohm meter so you can see when it changes state. Seal the sensor along with a thermometer in a plastic bag. Place the bag into cool water and add ice for further cooling. When the sensor changes state, record the temperature and ohm meter reading. Slowly warm the water and sensor until it changes state again. Record the temperature and ohm meter reading. The first set of readings is the low temperature limit set point and the second is the temperature at which heat collection can restart.

2. After checking the thermal switch, connect it to the controller or pump circuit and retest by varying the temperature as described, and verify that the proper response occurs.

Test Procedure for Variable Resistance Types

1. If freeze protection circuit uses a thermistor, nickel wire or film as its sensor, then a variable resistor whose resistance range passes through that of the low temperature set point should be connected to the collector sensor inputs. A resistor with a value somewhat less

than the collector freeze point should be connected to the storage input. With the appropriate load connected to the controller, connect the controller to the power input. The variable resistor should be varied above and below the freeze protection set point. Verify that the appropriate response occurs at the temperatures and resistance values specified by the manufacturer.

High Temperature Limit Protection

High temperature limit switches are used in solar systems either to protect collectors, storage tanks or as a secondary safeguard against failure of the mixing valve on the outlet to load.

Control logic should be set up so that the temperature limit switch will not inhibit the initial start up of the collector loop pump, but will activate if, after a reasonable length of time, the collector temperature has not fallen.

For closed loop glycol systems, the high temperature limit or control logic may be used to divert flow to a heat purge coil.

High Temperature Protection for Storage Tanks

High temperature limit switches are used to protect storage tanks from over temperature conditions. In some cases, a tank temperature limit can serve as a secondary protection against scalding temperatures being delivered to load if the mixing valve fails.

High Temperature Limit Switch Checkout

The checkout procedure is similar to that for freeze protection. The switch or sensor is immersed in hot water, which is heated until the device activates and then cooled until it reverses. The temperatures and resistances for these points are recorded and checked against the specifications.

4.3 GENERAL SYSTEM DIAGNOSTIC PROCEDURE

The performance of a solar system depends on the interaction of all system components, outside conditions, and the load imposed on the system.

There are cases in which a general decrease in the performance of a system is indicated by a decrease in system operating time, temperature differences, measured energy collected, or by an increase in the required auxiliary energy. In some cases, the particular problem cannot be isolated by the operator. The following is a general diagnostic procedure which can, in most cases, isolate the causes.

Carrying out this procedure requires some knowledge of solar systems and a number of portable instruments; therefore, a troubleshooting technician or engineer may be required.

1. The first step is a visual inspection of the system paying special attention to such items as completeness and condition of insulation and whether the collectors are clean and free of new shading.

2. Verifying flow rates.

   The operating flow rates in each loop should be checked by the means provided. This may be by using pump differential pressures or by reading a flow meter if one is installed in the particular loop. (See commissioning procedure.)

3. If the flow rate in any loop in the system is lower than specified, the flow restriction can be isolated by checking the pressures at the monitoring points provided in the system and comparing these with the commissioned values.

4. If the flow rates in all points of all loops are as specified, check the fluid temperatures at each monitoring point on a clear sunny day.

5. Verify the flow balance through the collector banks.

The face temperature of each collector should be checked by feel or, preferably, with a pyrometer. Collectors that are significantly warmer or cooler than their neighbours indicates flow blockages and stagnation or high flows respectively.

It is a good idea to check the bank temperature balance by the method shown in the commissioning procedure.

6. Verify the effectiveness of the heat exchanger as in the commissioning procedure. A reduced effectiveness could indicate scaling of the heat exchanger surfaces.

7. Perform the preliminary thermal performance test as shown in the commissioning procedure and compare the efficiency with the commissioned values. This will detect degradation of the collectors' performance.

8. Check the calibration of the control system as described in "Troubleshooting Solar Controls."

If satisfied that the operating characteristics of the system are normal, investigate the non-operating features.

9. Isolate the system from load and bring the storage temperatures up during the day. Read the storage temperature at nightfall and shut off the system. Check the storage temperature in the morning. If the storage temperature has dropped significantly, suspect damaged or wet insulation, or reverse thermosyphoning (usually the result of a faulty check valve).

5.0 PERFORMANCE MONITORING

The selection of performance monitoring equipment is based on the system configuration and type of auxiliary heating equipment used.

The monitoring equipment is used for determining the overall performance of a solar heating system with the energy delivered to the load by the solar heating system being the primary consideration.

The designer of a solar heating system must carry out three tasks:

1. Determine, based on the system configuration, the appropriate location for monitoring equipment,
2. Determine the appropriate specifications for the monitoring equipment,
3. Produce a monitoring reporting form for use by the system operator.

Sometimes it is advantageous to measure other parameters and calculate, indirectly, the energy supplied by the solar system. This is the case when the temperature difference through the solar portion of the system is small and difficult to measure accurately.

If the solar energy delivered to the load is being determined indirectly, factors required for the calculation of the solar energy delivered must be determined and provided as part of the monitoring reporting form.

Various options for measuring the solar energy delivered by a solar heating system are presented here in their order of preference. One should only select a particular option if all previous ones are unacceptable.

An example of the format for the performance monitoring form to be developed for each system is shown in Figure 5.1.

Figure 5.1

MONITORING MONTHLY REPORT

PROJECT NAME:

PROJECT NUMBER:

DATE:

Please fill in energy quantities indicated below:

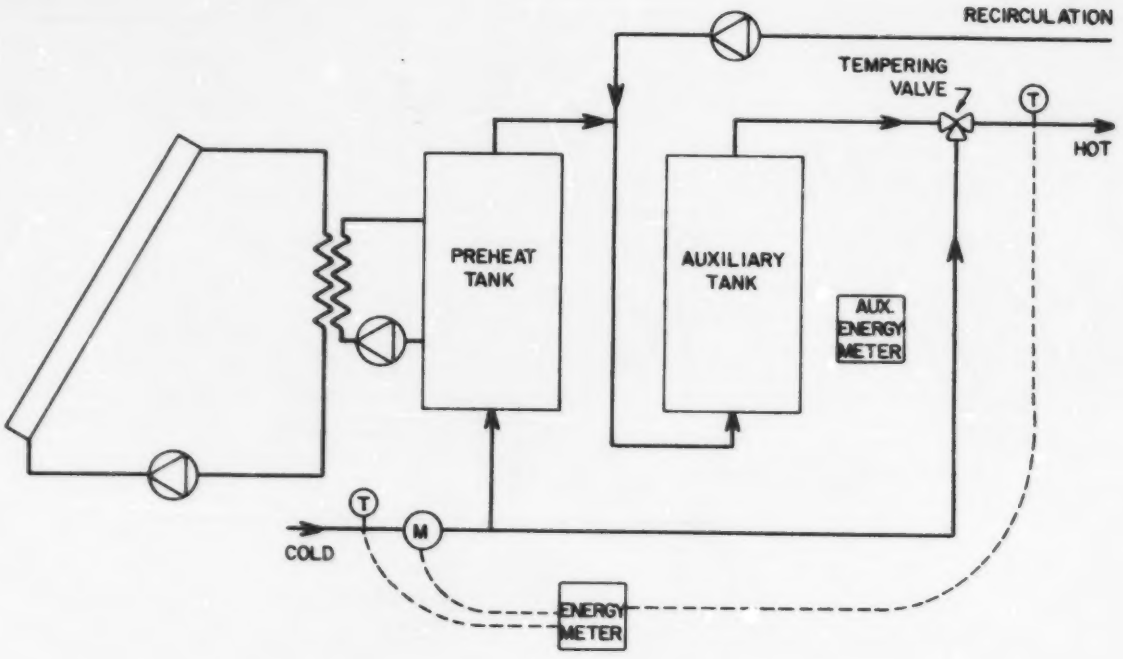
SOLAR ENERGY INPUT (meter number)

AUXILIARY ENERGY INPUT (meter number)

TOTAL ENERGY INPUT (meter number)

RECORD OF SYSTEM PROBLEMS:
(Briefly explain any system problems encountered)

FIGURE 5.2
PERFORMANCE MONITORING: OPTION 1



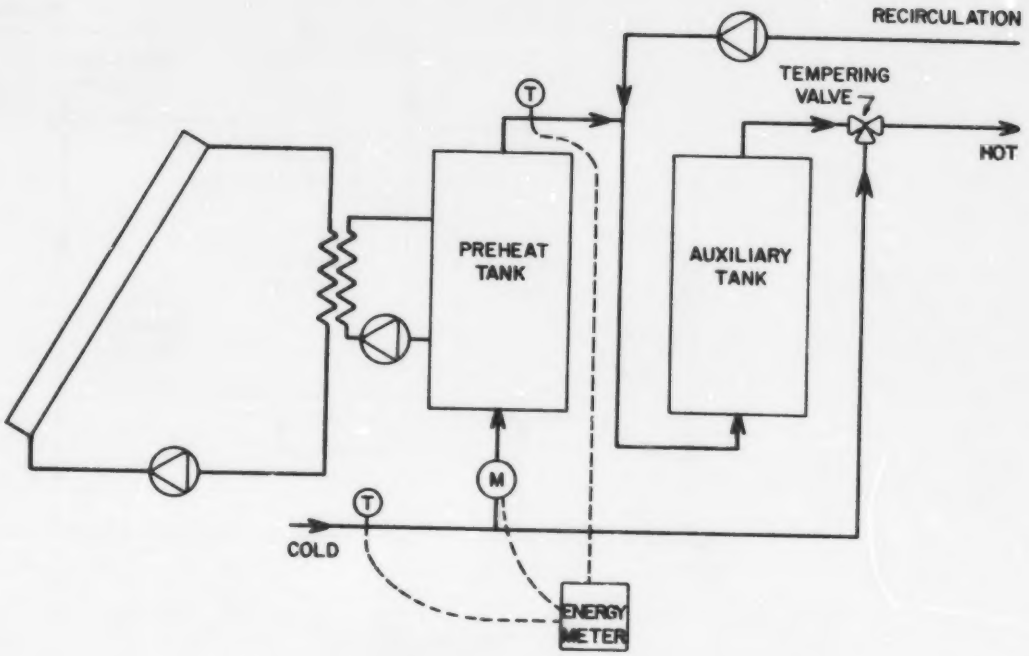
METERS REQUIRED:

1 meter for overall energy supplied by the system (integrating heat meter with cold water flow meter)
2 meter for auxiliary energy - gas
- electric

REASONS FOR REJECTION OF THIS OPTION:

1 application does not involve the heating of cold water
2 auxiliary energy difficult to measure - steam
- oil
- wood
3 energy from collector loop supplied to more than one load

FIGURE 5.3
PERFORMANCE MONITORING: OPTION 2



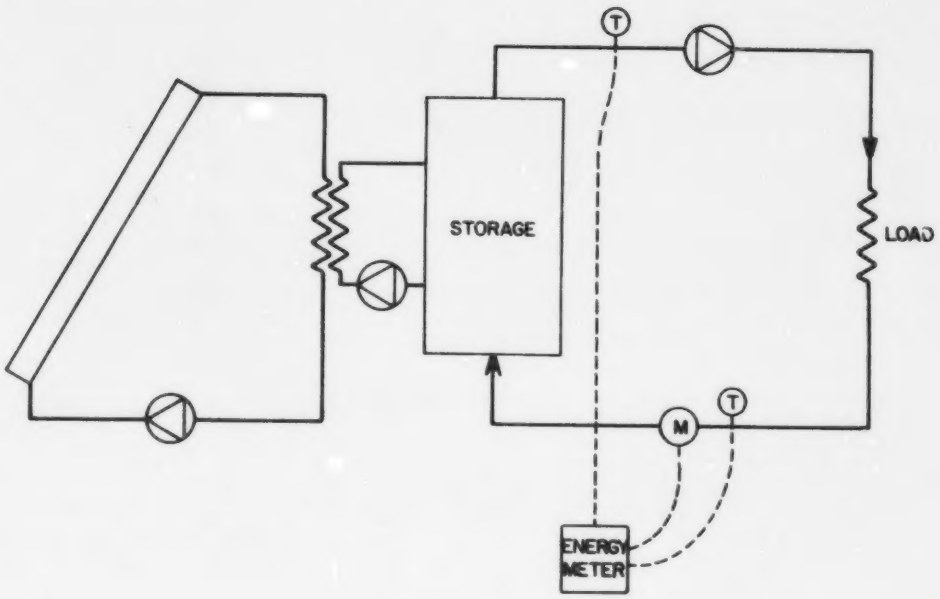
METERS REQUIRED:

1 meter for energy supplied by the solar system after the pre-heat tank (integrating heat meter with cold water flow meter)

REASONS FOR REJECTION OF THIS OPTION:

1 application does not involve the heating of cold water
2 energy from collector loop supplied to more than one load
3 if the load side flow rate is so high that the temperature rise is very small and cannot be measured accurately.

FIGURE 5.4
PERFORMANCE MONITORING: OPTION 3



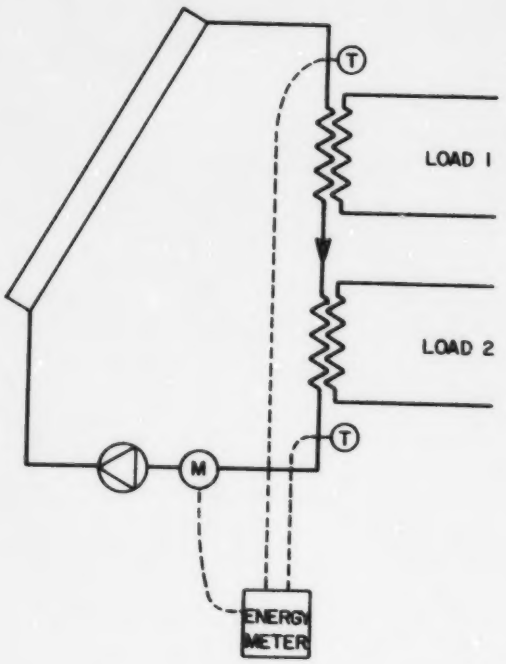
METERS REQUIRED:

1 meter for energy supplied by the solar system after the pre-heat tank (integrating heat meter with HOT water flow meter)

REASONS FOR REJECTION OF THIS OPTION:

1 energy from collector loop supplied to more than one load
2 if the load side flow is so high that the temperature rise is very small and cannot be measured accurately

FIGURE 5.5
PERFORMANCE MONITORING: OPTION 4



METERS REQUIRED:

1 meter for energy supplied by the solar system to storage or load (integrating heat meter with HOT water or HOT GLYCOL flow meter)

5.1 INSTRUMENTATION SPECIFICATIONS

The following list of instrumentation includes instruments commonly in use with solar heating systems, however, the list is not exhaustive. Before choosing a particular instrument, its specification and performance record should be investigated carefully. Other instruments which have similar specification may also be acceptable, however, the Solar Programs Office should be consulted for advice. In selecting performance monitoring equipment, one should consider not only the reliability record for each device, but also the availability of service.

Integrating Heat Meters

Siemens

Siemens Calorimetric Counter (Heat Integrating Unit)
Model: M72131-A124-A2
Model: M72131-A121-A2

This is an integrating heat meter which requires inputs from a pulse output flow meter and two platinum RTD's. Care must be taken to match the pulse output frequency of the flow meter to the exact model of integrator ordered.

Typical Platinum RTD's are:

Heraeus Resistance Thermometers
Model: WGN9 1 Pt 100 to DIN 43 760

Typical acceptable flow meters are:
Neptune Type "S" Green Seal for 5/8 inch to 2 inch applications
Neptune Crest Green Seal for 3 inch to 6 inch applications
Both of these types of meters must be equipped with a model 34 impulse switch and model 157 register.

Specifications for the heat integrating unit and resistance thermometers are available from:

Alpha Controls and Instrumentation
160 Gibson Drive, Unit 7
Markham, Ontario
(416) 499-1672

Specifications for the flow metering equipment are available from:

Neptune Meters Limited
3526 Lakeshore Blvd. West
Toronto, Ontario
(416) 259-4211

Ista

This company makes a complete range of heat metering equipment and supplies the integrating units, flow meters and temperature probes.

Of particular interest are their small units for applications requiring flow meters of up to one inch diameter pipe sizes.

Specifications for this equipment are available from:

Con-Serve Group Limited
18 Gradwell Drive
Scarborough. Ontario
(416) 266-9635

Valmet

Valmet Heat Meter Model 5EV-

This company offers a complete range of heat metering equipment complete with flow meters and temperature probes. Because the integrating units use inputs from standard pt 100 RTD's and pulse output flow meters, RTD's and flow meters of other manufacturers may be used.

Specifications for this equipment are available from:

AALTO Equipment Limited
500 Duplex Avenue
Suite 1503
Toronto, Ontario
(416) 484-0729

Rho Sigma

Rho Sigma BTU Meter RS805

This is a heat metering integrator which has displays of total BTU and U.S. gallons. Temperature sensing is done with thermistors. Flow measuring can be done with a meter supplied by Rho Sigma for flows of up to 30 U.S. gpm or with other standard pulse output meters.

Specifications are available from:

E. S. Gallagher Sales Limited
44 Eugene Street
Toronto, Ontario
M6B 3Z4
(416) 789-5385

or:

Solarsystems Industries Limited
2-11771 Horseshoe Way
Richmond, British Columbia
(604) 271-2621

Auxiliary Energy Measurement

Auxiliary energy usage can be measured with standard kilowatt-hour meters or displacement gas meters. Where possible these meters should have digital readouts.

Kilowatt-hour meters

A wide variety of kilowatt-hour meters are available from most industrial electrical suppliers, however, most are manufactured by either:

1. Sangamo Canada
   215 Laird Drive
   Toronto, Ontario
   M4G 3X1
   (416) 425-3330

2. Canadian General Electric
   396 Attwell Drive
   Toronto, Ontario
   M9W 5C3
   (416) 675-7500

Gas meters

Gas meters of various sizes are available for use with either natural gas or propane. These meters are available from:

1. Rockwell International of Canada Limited
   41 Massey Road
   Guelph, Ontario
   N1H 7M6
   (416) 363-8070

2. Canadian Meter Company Limited
   3037 Derry Road West
   Milton, Ontario
   1-800-268-5043

APPENDIX A MODULES AND THEIR REQUIRED INSTRUMENTATION

A 1 Introduction

The concept employed in the specification of instrumentation is to first divide the solar system into modules. For each of these modules, standard instrumentation and test points are then specified.

The instrumentation and test points are to be used during the commissioning, operational monitoring and the troubleshooting of the system.

The modules employed include:

- collector array,
- pump,
- heat exchanger,
- storage system,
- control valve,
- auxiliary heater,
- control system.

By studying the schematic of a typical solar system shown in Figure A1 and doing an inventory of its main elements and components, it is seen that the system may be broken into the modules shown in Figure A2.

The concept of breaking a solar system into its component modules is an important one for the system designer to understand, since it allows many different system configurations to be analyzed and inventoried with a common approach.

After the system has been divided into its appropriate modules, the required instrumentation and test points are then known for each module. It is then a simple task of recombining the modules into the original system configuration and eliminating any duplication of instrumentation

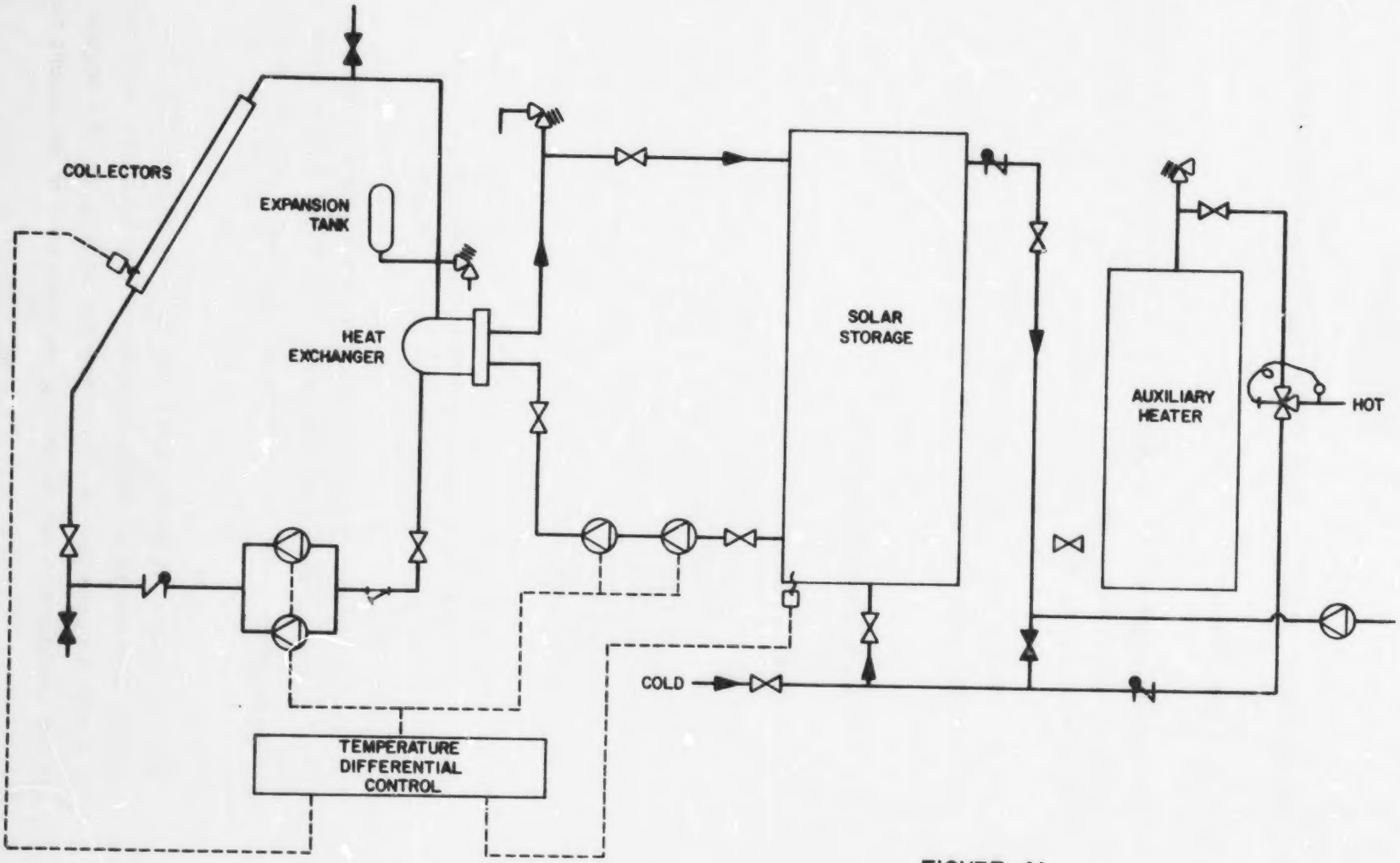


FIGURE A1
Typical Solar System

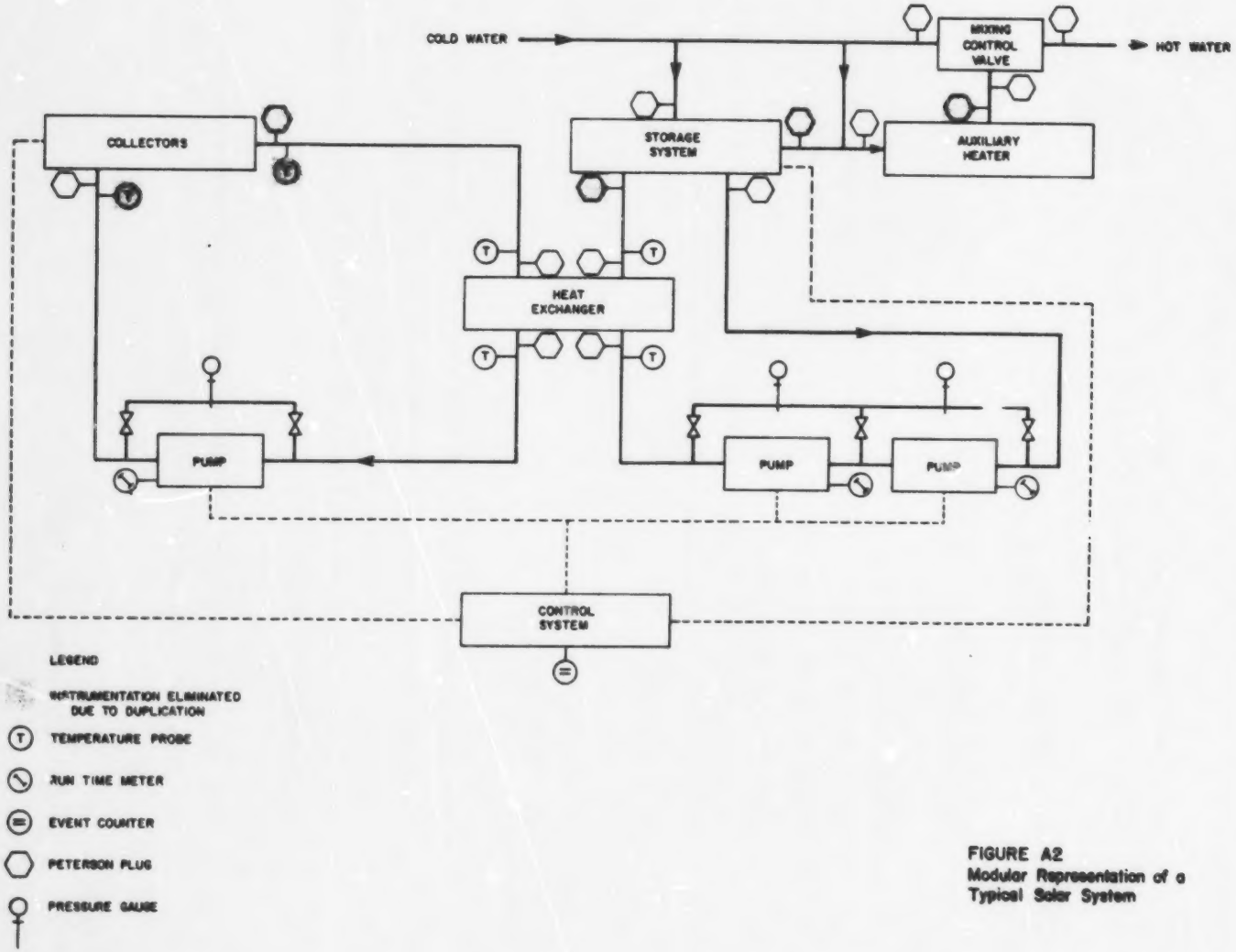


FIGURE A2
Modular Representation of a Typical Solar System

between the various adjoining modules (also shown in Figure A2.)

Peterson Plugs are useful to install in areas of the system where temperature or pressure readings will be required less frequently.

A 2 System Modules

COLLECTOR ARRAY MODULE

The collector module (Fig. A3) consists of a set of collectors joined in series and/or parallel. Temperature probes and Peterson Plugs will be required in the supply line to the collector array and in the return line from the collector array. A collector high limit thermostat may be installed in the return line to activate a signal when the temperature reaches 95°C. In addition, a flow indicator should be installed in the collector loop.

PUMP MODULE

The pump module consists of one or more pumps having common suction and discharge lines. Pumps in series should be treated as separate pump modules. At each module, the system static pressure, the discharge pressure and the pump head must be measured. Alternative instrumentation is illustrated in Figure A4.

A pump run time meter will be installed on each separately operable pump which is not intended to run continuously.

HEAT EXCHANGER MODULE

The heat exchanger will be set up in one of two common configurations. In one case, the module will consist of a heat exchanger, two supply lines and two return lines (Fig. A5). This configuration is used for counter flow, parallel flow and cross flow heat exchangers. In the second case, for

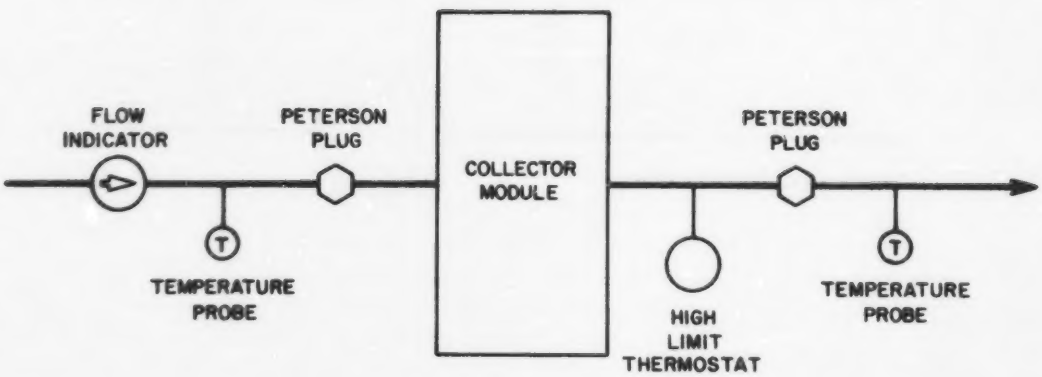


FIGURE A3
Collector Array Module

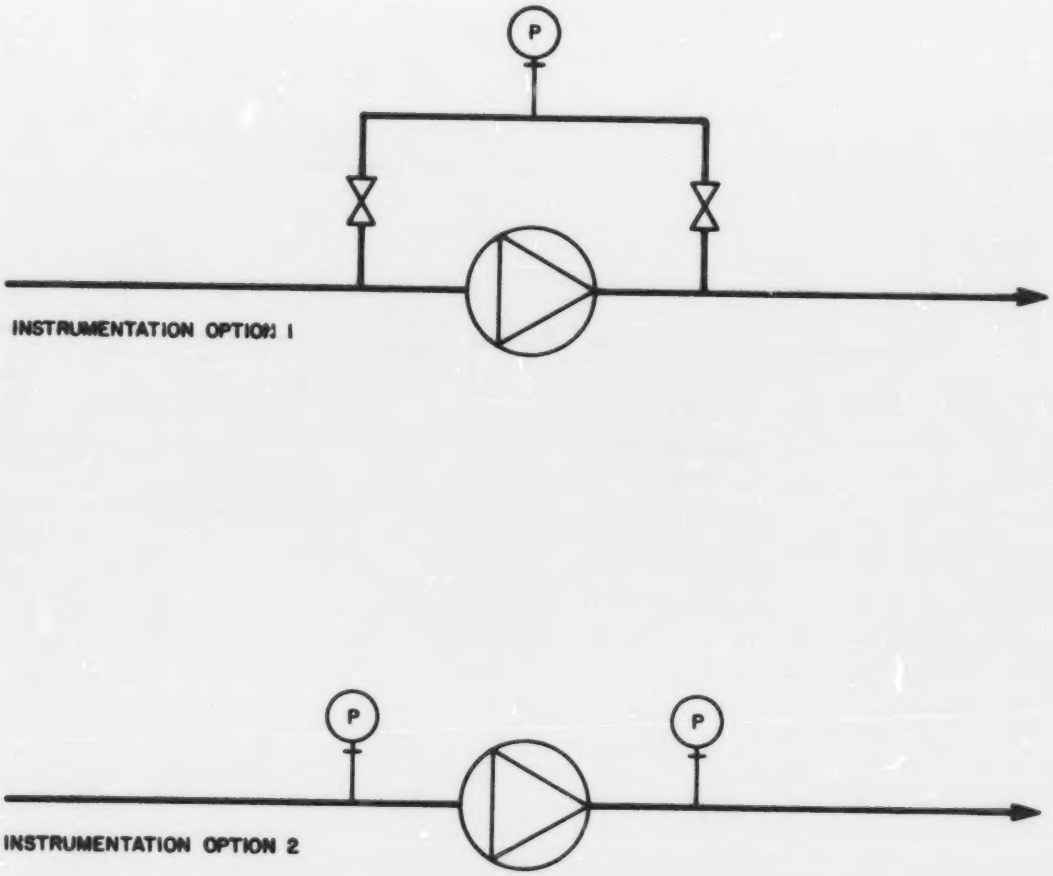


FIGURE A4
Pump Module

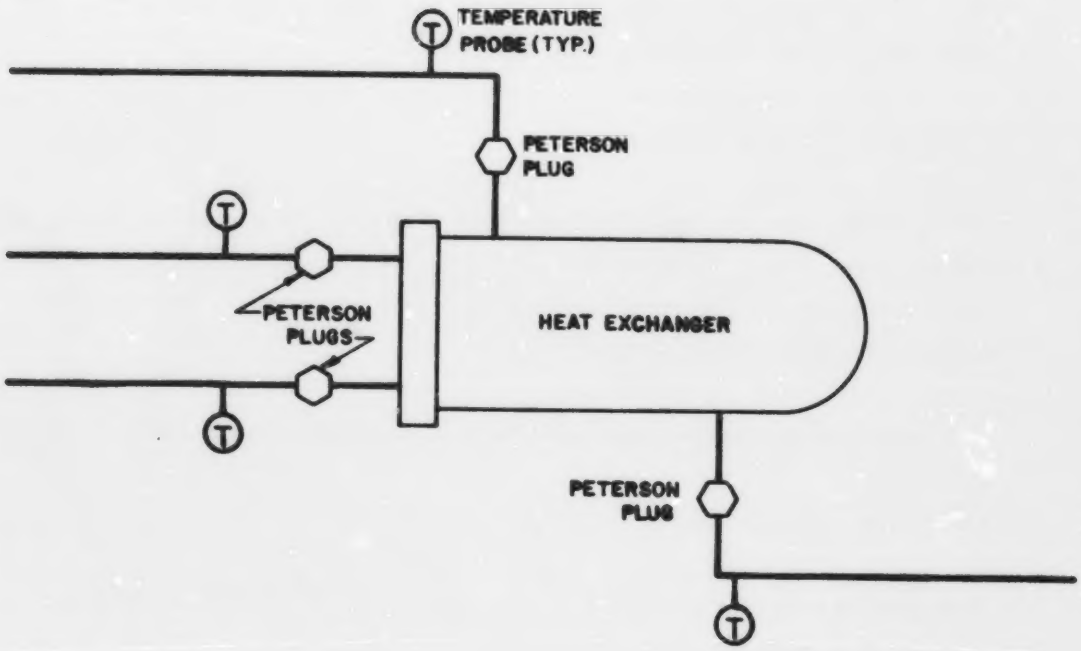


FIGURE A5
Heat Exchanger Module
(External)

wrap-around and coil-in-tank heat exchangers, the module will consist of the tank and the coil (Fig. A6).

The inlet and outlet lines of the primary and secondary circuits will be equipped with temperature probes and Peterson Plugs.

Wrap-around and coil-in-tank models will also require measurement of the fluid temperature surrounding the heat exchanger.

STORAGE SYSTEM MODULE

The storage module (Fig. A7) consists of a storage tank and the supply and return lines to and from the tank. The number of inlets and outlets varies with the design of the particular storage system, although, will generally consist of either one or two of each.

The inlet and the outlet lines will each be equipped with a Peterson Plug.

CONTROL VALVE MODULE

Any control valve of a mixing or diverting type is to be considered a module (Fig. A8).

A Peterson Plug is required in each line to the valve.

AUXILIARY HEATER MODULE

The auxiliary heater module (Fig. A9) consists of an auxiliary heater with an inlet line and an outlet line. The inlet and outlet lines will be equipped with Peterson Plugs.

CONTROL SYSTEM MODULE

An event counter is required for each differential control module.

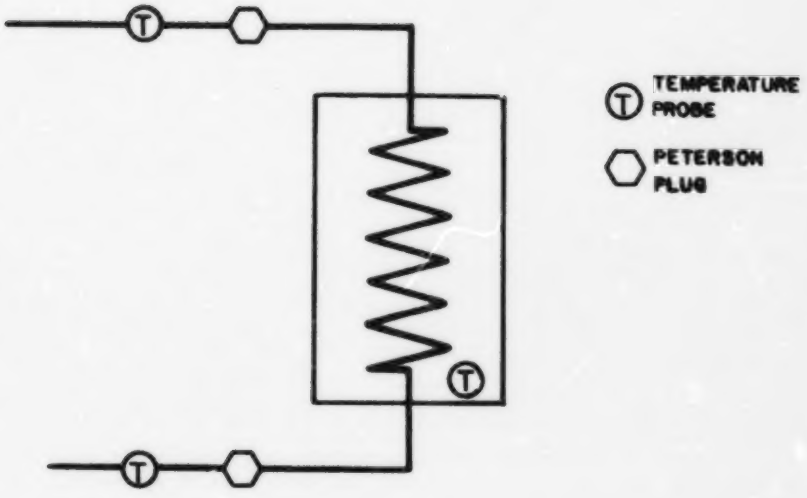


FIGURE A6
Internal Heat
Exchanger Module

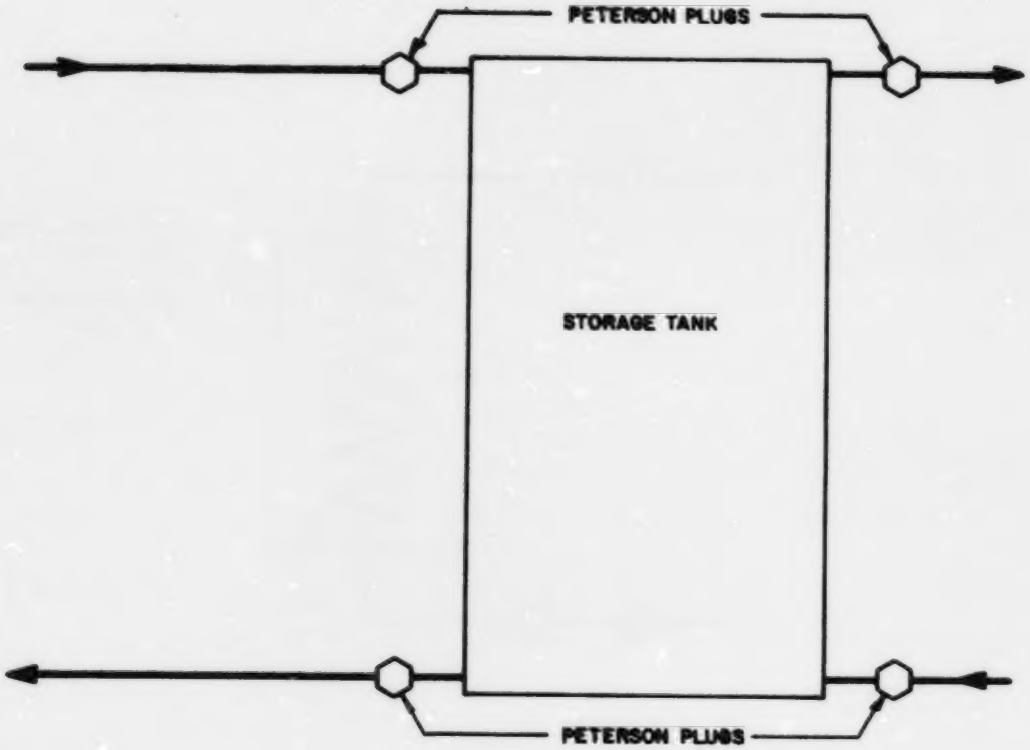


FIGURE A7
Storage System
Module

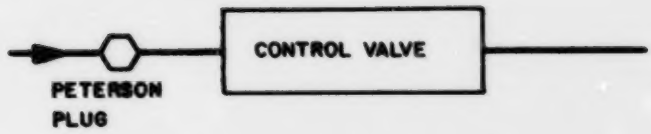


FIGURE A8
Control Valve Module

FIGURE A9
Auxiliary Heater
Module

APPENDIX B INSTRUMENTATION SPECIFICATIONS AND INSTALLATION

In Appendix A, a need was established for the following instrumentation:

- Peterson Plugs
- Temperature probes and readouts
- High limit thermostat
- Flow indicator
- Pressure gauges
- Run time meters
- Event counters

Specifications for these instruments and guidelines for their installation are outlined in this section.

Peterson Plugs

Peterson Plugs, part Number 110, are manufactured by Peterson Equipment Co., Richardson, Texas. They are available through:

Ontario Mechanical Sales and Service Inc.
4325 Steeles Avenue West
Downsview, Ontario
M3N 1V7
(416) 663-5530

and

C. R. Wall & Co., Inc.
East Lambeth Plaza
Campbell Street & No. 2 Highway
P.O. Box 280
Lambeth, Ontario
N0L 1S0
(519) 652-2490 TELEX 064-78385

These devices are installed in elbows in all cases. Figure B1 illustrates the installation.

Temperature Probes and Readouts

Locations that require frequent (daily) temperature readings will require a permanently installed probe and temperature readout. In locations where the temperature is read less frequently, the probe will be temporarily inserted into Peterson Plugs when required. High accuracy temperature devices are required since most readings are used to determine temperature differentials. To obtain meaningful measurements, resistance temperature detectors should be used due to their increased level of initial accuracy, linearity, stability and standardization.

Probe type: Platinum RTD (DIN 43760)
wire-wound or thin-film elements

Minimum accuracy: @ 0°C plus or minus .3°C
@ 100°C plus or minus .6°C

Inexhaustive list of suppliers:

HyCal Model RTS-30, Platinum RTD
Intertechnology, 1 Scarsdale Road
Don Mills, Ontario

Enercorp Model Precision Pt-100 RTD
P.O. Box 20, Station U
Toronto, Ontario

Omega Engineering Model PR-12
Platinum-100 RTD
1 Omega Drive
Stamford, Connecticut U.S.A.

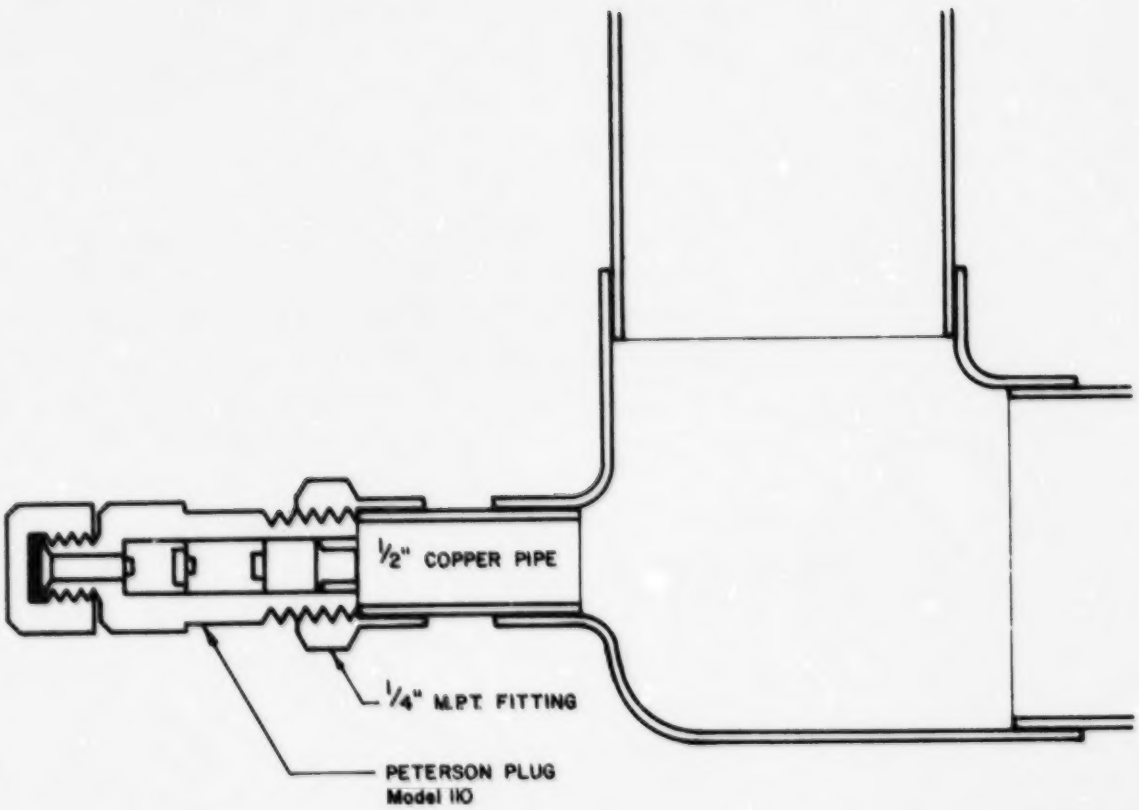


FIGURE B1
Peterson Plug Installation

Readout type:

Digital temperature readout,
3 or 4 wire lead-resistance
compensated Standard Platinum
RTD (DIN 43760)

Minimum requirements:

Range - $0^{o}C$ - $100^{o}C$
Resolution - $.1^{o}C$
Accuracy - .1% of scale; plus or minus one digit
Sampling time - 1 second
Protection from - open RTD sensor line
- shorted RTD sensor line
- RTD short to AC line

Inexhaustive list of suppliers:

Doric Model 410A, 3 1/2 Digit Indicator
Intertechnology, 1 Scarsdale Road
Don Mills, Ontario

Enercorp Model PDAW - 48 RTD Indicator
P.O. Box 20, Station U
Toronto, Ontario

Thermo Electric Analogic / ELS RTD
Indicators, 12 Rutherford
South Brampton, Ontario

Omega Engineering Model 199 RTD Meter
1 Omega Drive
Stamford, Connecticut U.S.A.

Figures B2 and B3 illustrate a permanently installed RTD. Note the following characteristics of the installation:

- temperature wells are to be located in 90^{o} elbows in the piping run (as illustrated in Figure B2) or on an angle in a straight run of pipe (as illustrated in Figure B3) to ensure that the probe is fully exposed to the true temperature.

- temperature wells are constructed of stainless steel and must not decrease the flow area by more than 10% (enlarged section of piping may have to be installed to prevent this from happening.)

- use silicone heat-conductive compound to ensure good thermal contact between the element and the system fluid.

- affix metal junction boxes or heads to the temperature wells to protect the sensor unit wiring and the terminal block junctions.

- design these boxes to allow access to the temperature sensors for service and replacement.

- use a packing nut and gland to affix the temperature sensor to the thermal well and to reduce the external ambient heat effect on the sensor.

- if the probe is installed in a cold water line, apply waterproof sealant around the point where the sensor wires pass through the packing nut to prevent condensation in the well and, therefore, the eventual failure of the element.

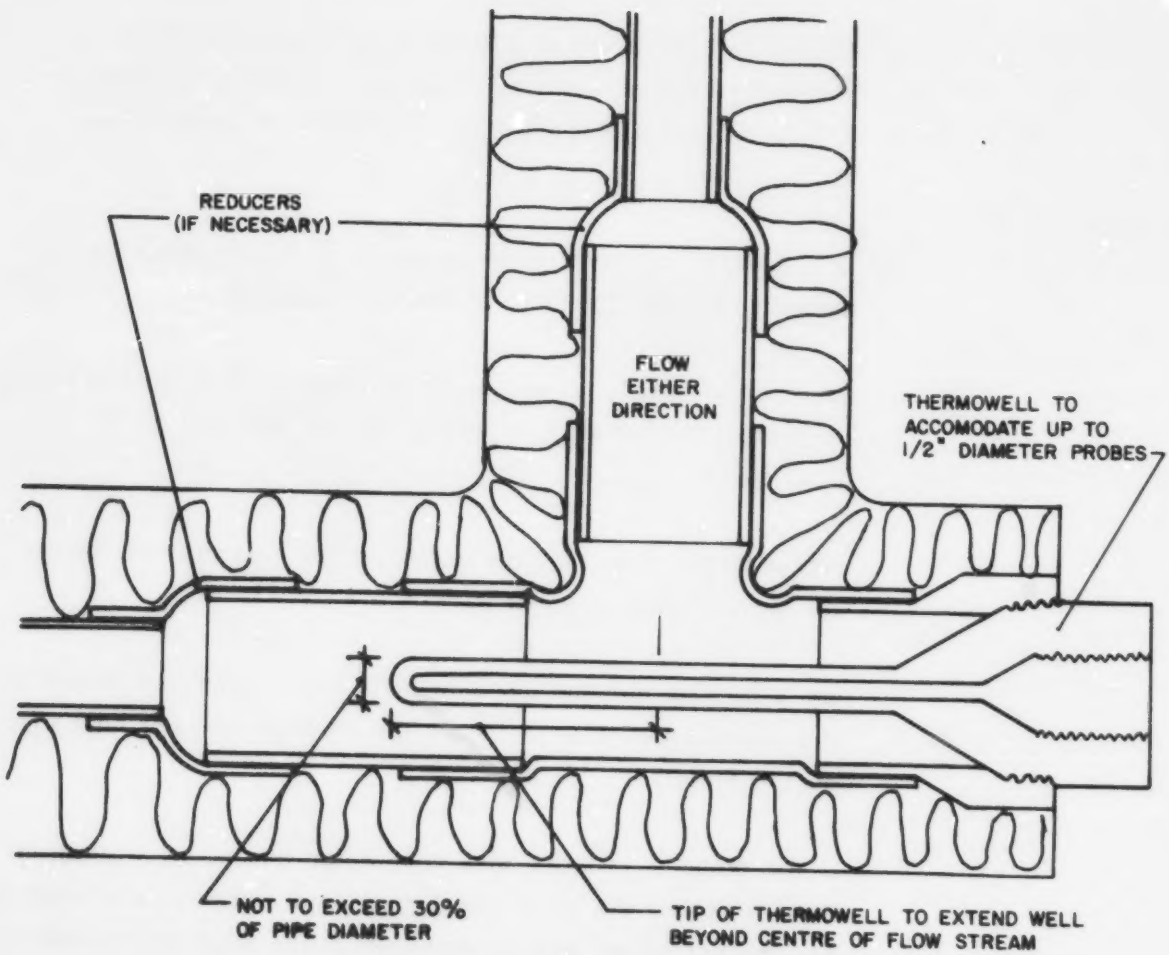


FIGURE B2
RTD Installation in a
90° Elbow

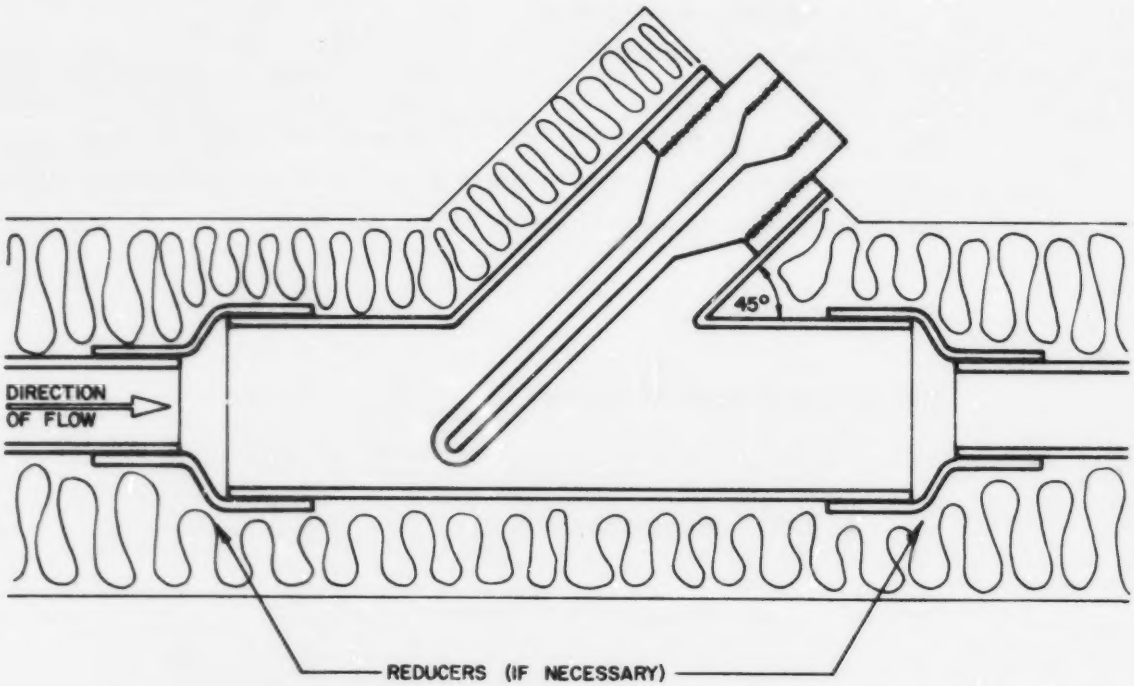


FIGURE B3
RTD Installation in a
Straight Run of Pipe

High Limit Thermostats

The high limit thermostat requires a:

- well assembly
- capillary sensing bulb
- rain proof encloser

Use a "Penn" A19 ABC 11 or the equivalent. Install the thermostat at the collector outlet. Wire through the latching relay to the collector system status panel to indicate the status of the alarm.

Flow Indicators

Minimum specifications include:

- 700 kPa pressure rating,
- 100^{o}C temperature rating.

Inexhaustive list of suppliers include:

RADA Mechanical Products Ltd.
Markham, Ontario

DRY-CON Inc.
840 Halpern Ave.
Dorval, Quebec

HIGGINSON Equipment Sales Ltd.
Burlington, Ontario

Pressure Gauges

Locations that require frequent (daily) pressure readings will require a permanently installed gauge. In locations where the temperature is read less frequently, the gauge will be temporarily inserted into Peterson Plugs when required.

Select gauges equivalent to "Trerice" or "Winters" with a sufficient range for the solar system. The gauges can be provided with an isolation valve.

The pressure gauge should be connected to the line through a tee fitting. Installation details are shown in Figure B4.

Run Time Meters

Characteristics of the required run time meter include:

- electro-mechanical, 110 volt, AC synchronous motor-driven counter
- non-resettable, 6-digit hour and tenths of hour indicator
- CSA approved

Use a Bach Simpson Number 1357 ETIF or equivalent.

Install in accordance with the manufacturer's instructions.

Event counters

Characteristics of the required event counter include:

- electro-mechanical, 110 volt
- non-resettable, minimum 6-digit readout
- CSA approved

Use a "Hecon" AO - 040 or equivalent.

Install in accordance with the manufacturer's instructions.